

# An Overview of the CLEVER Model: the real-time flood forecasting system for BC

— Challenges, science, operations, history and uncertainties















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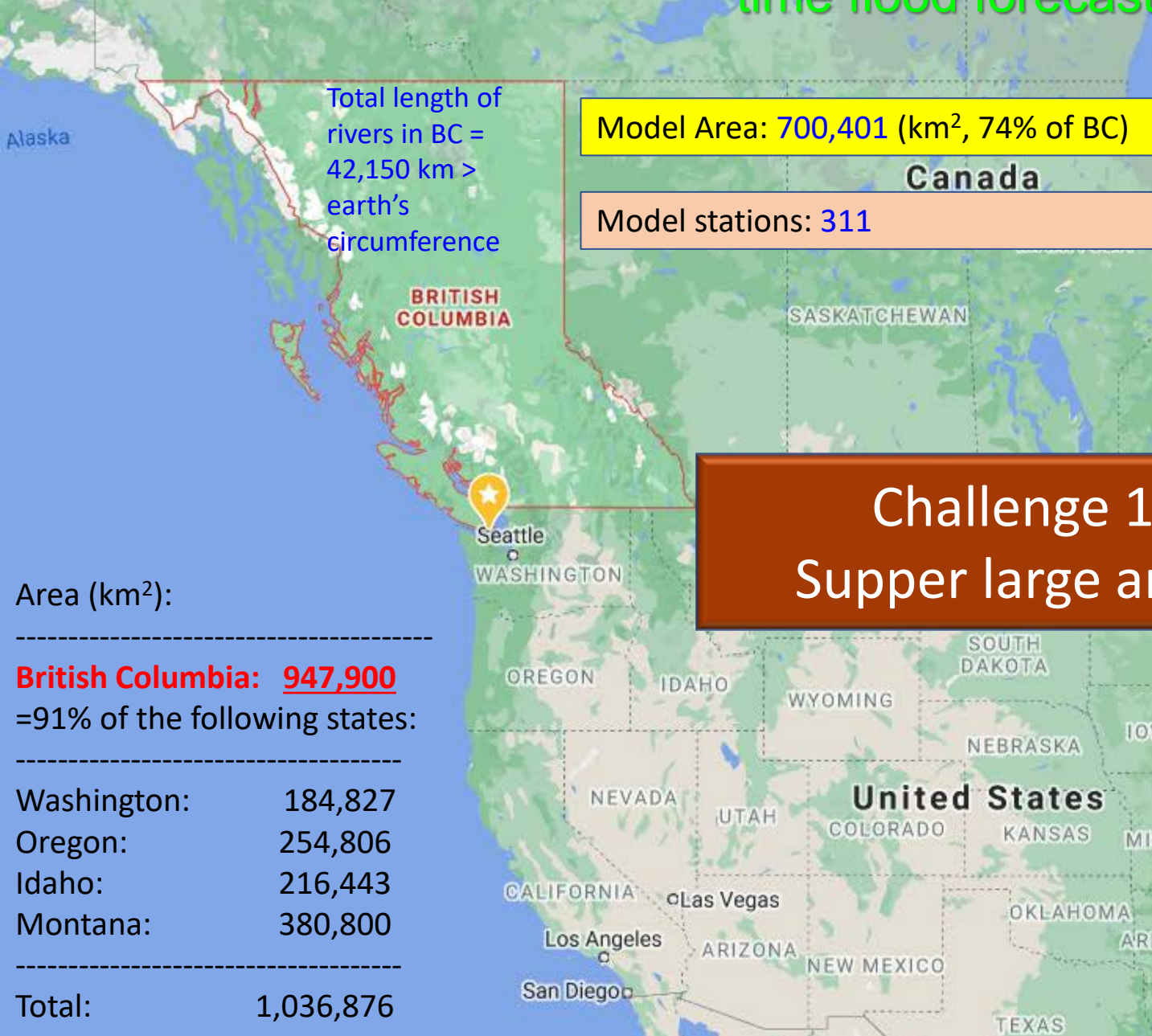
## Contents

1. Why the CLEVER Model – Challenges of real-time flood forecasting in BC 
2. Model structure 
3. Science: Distributed open channel routing – An improved kinematic wave scheme 
4. Science: Lumped watershed routing – An improved temperature-index snowmelt model 
5. Codes and user interfaces 
6. Input data and data assimilation 
7. Model calibration – flexibility to adapt to climate changes 
8. Producing forecasts – informative and easy to read 
9. Model history – developing, expanding and upgrading 
10. Post freshet review of model performance - statistics and flooding events 
11. Modeling uncertainties – understanding limitations 
12. Types of modeled stations 



# 1. Why the CLEVER Model – Challenges of real-time flood forecasting in BC

CLEVER MODEL BASINS (2021)



Total length of rivers in BC = 42,150 km > earth's circumference

Model Area: 700,401 (km<sup>2</sup>, 74% of BC)

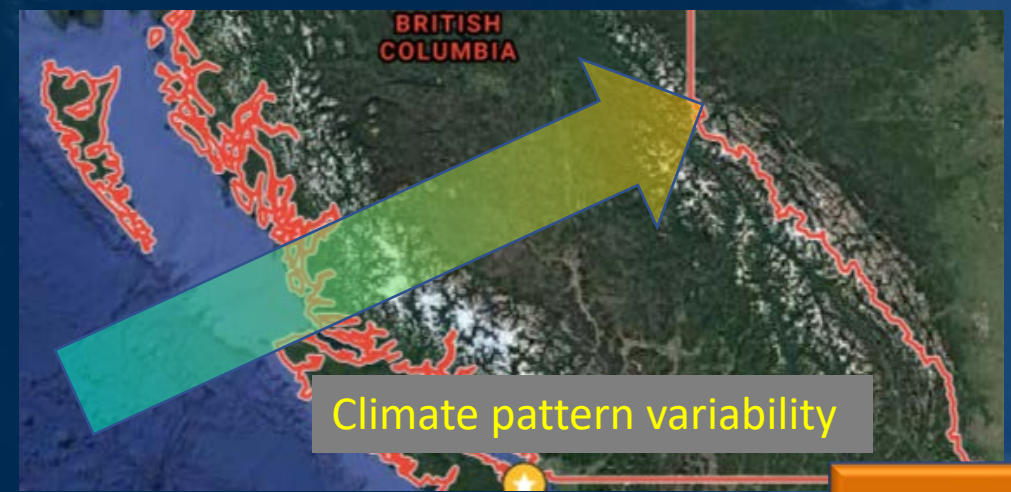
Model stations: 311

Challenge 1. Supper large areas

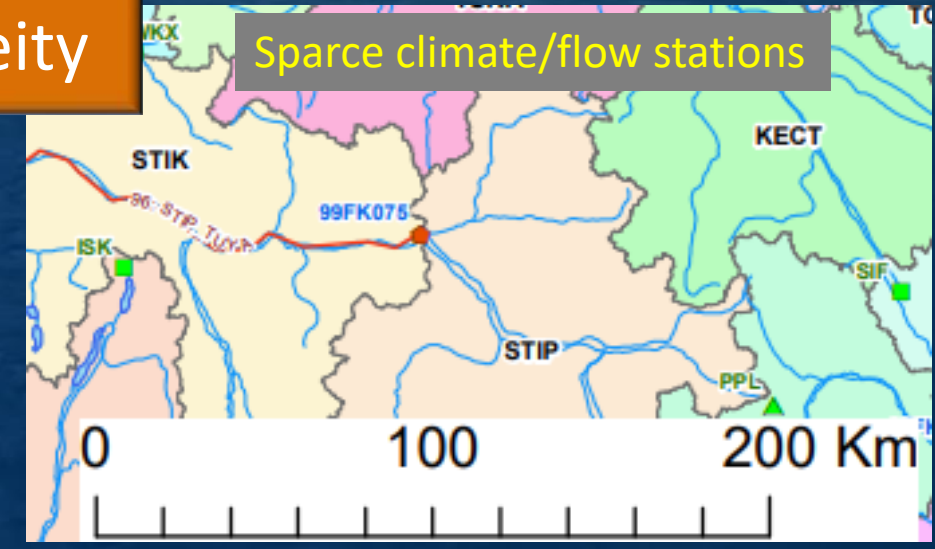
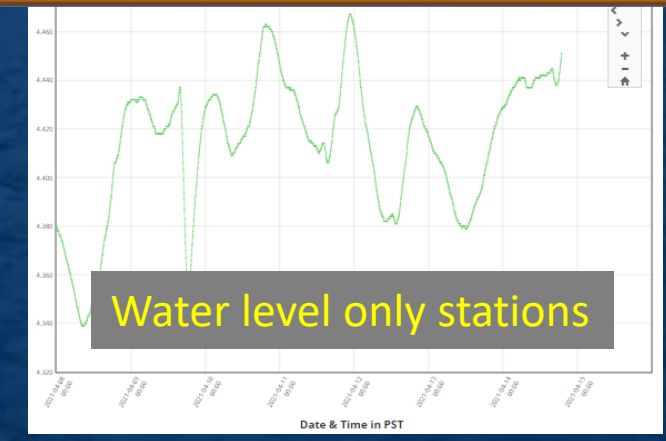
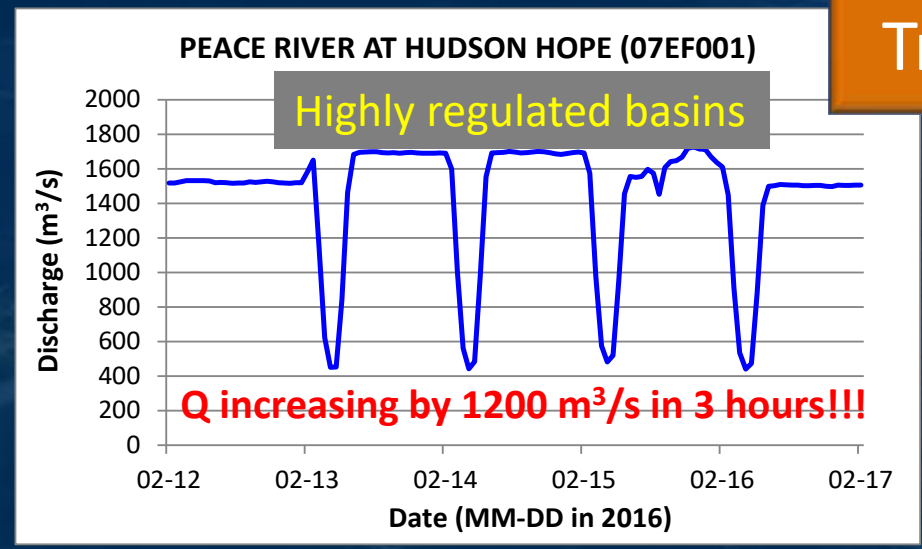




# 1. Why the CLEVER Model – Challenges of real-time flood forecasting in BC



## Challenge 2. Tremendous heterogeneity





# 1. Why the CLEVER Model – Challenges of real-time flood forecasting in BC



Stantec Consulting Ltd, 2014. River Forecast Performance Measures Development Project Final Report, Alberta Environment and Sustainable Resource Development, Edmonton, AB

**Table 3-1: Flood Forecasting Centre Staffing**

FFC	No., of Staff	Forecast Area (km <sup>2</sup> )	Staff per service area ratio	Forecast Population	Staff per population ratio
CBRFC	14	785,932 km <sup>2</sup>	~ 1:56,000	12.7 M	~ 1:1,000,000
UD&FC	23	7,770 km <sup>2</sup> **	~ 1:340	2.3 M	~ 1:100,000
FCDMC	***	13,985km <sup>2</sup>		3.9 M	
ASWFN		295,280km <sup>2</sup>		6.5M	
			1:4,600	8.0 M	~ 1:1,000,000
			1:7,800	5.3 M	~ 1:500,000
			1:600	0.5 M	~ 1:80,000
			1:170	985,000	~1:24,000
GRCA	41	7,000km <sup>2</sup>			
<b>BCRFC</b>	<b>4.5</b>	950,000 km <sup>2</sup>	~ 1:200,000	4.5 M	~ 1:900,000
BRFC	12	71,000 km <sup>2</sup>	~ 1:6,000	12.0 M	~ 1:1,000,000
HFC	12	650,000 km <sup>2</sup>	~ 1:50,000	1.3 M	~1:1,000,000
ARFCWB*	50	Not available		22.7M	
HIC*	25	Not available		6M	

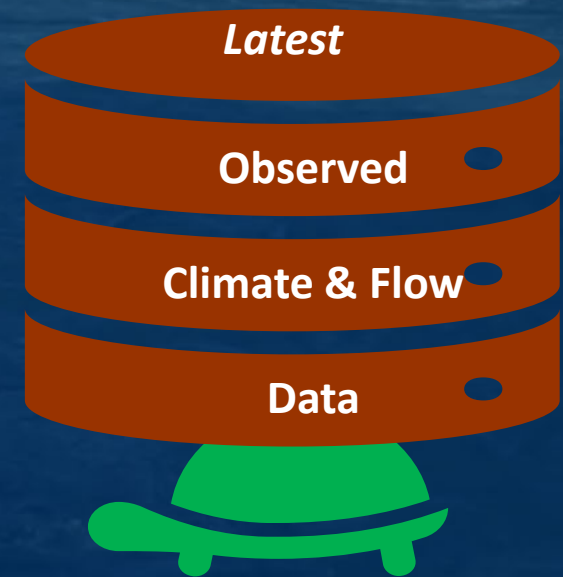
Challenge 3.  
Very limited resources



# 1. Why the CLEVER Model – Challenges of real-time flood forecasting in BC



Challenge 4.  
Very limited time for modeling (about 90 minutes each day)





# 1. Why the CLEVER Model – Challenges of real-time flood forecasting in BC



Challenge 4.  
Very limited time for modeling (about 90 minutes each day)

Challenge 3.  
Very limited resources

Challenge 2.  
Tremendous heterogeneity

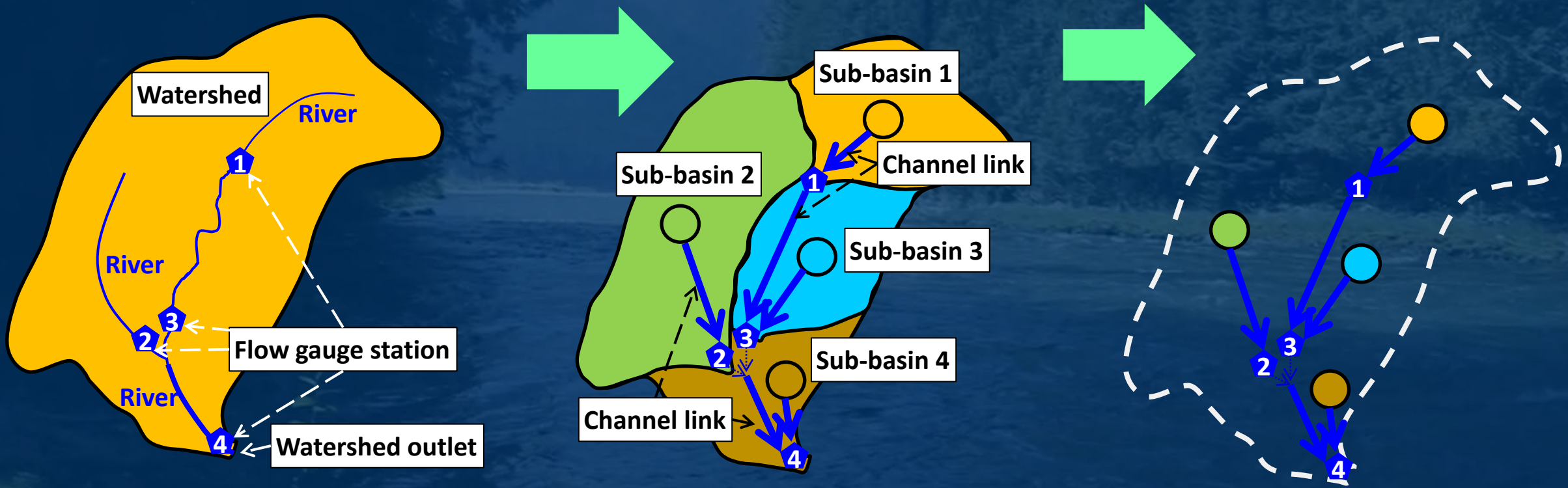
Challenge 1.  
Supper large areas



Channel Links Evolution Efficient  
Routing (CLEVER) Model

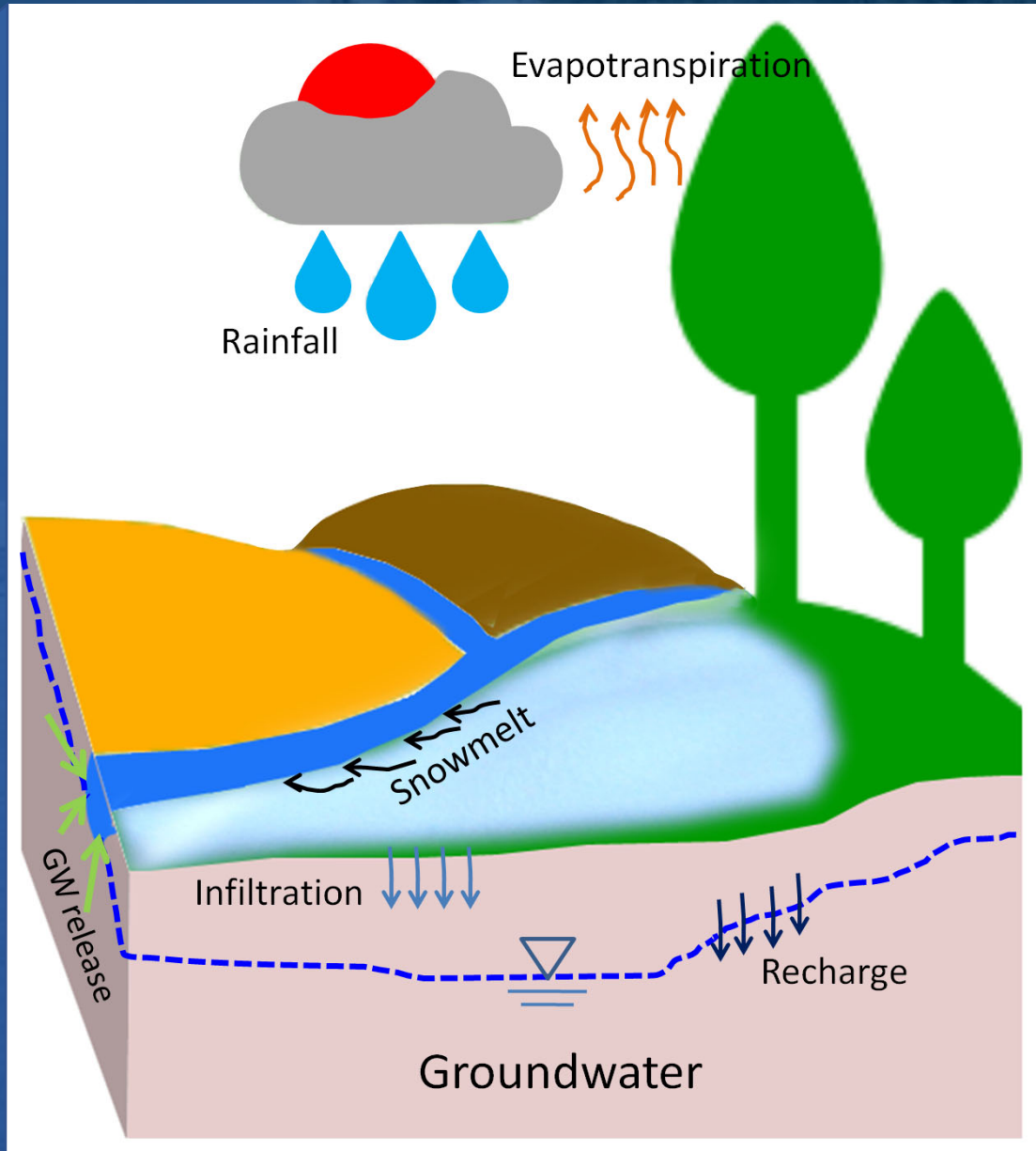


## 2. Model structure – watershed simplification

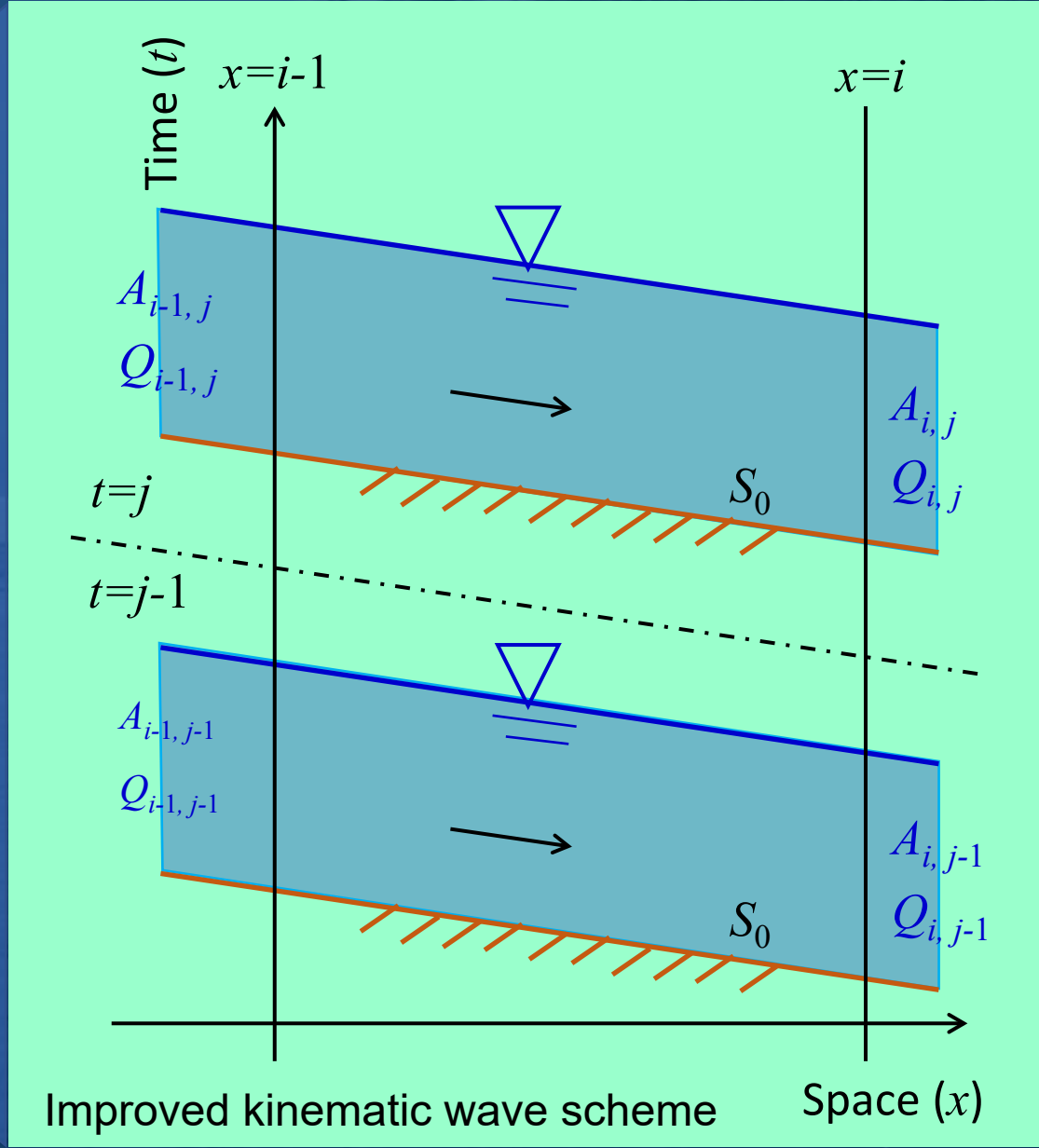




## 2. Model structure – Watershed routing

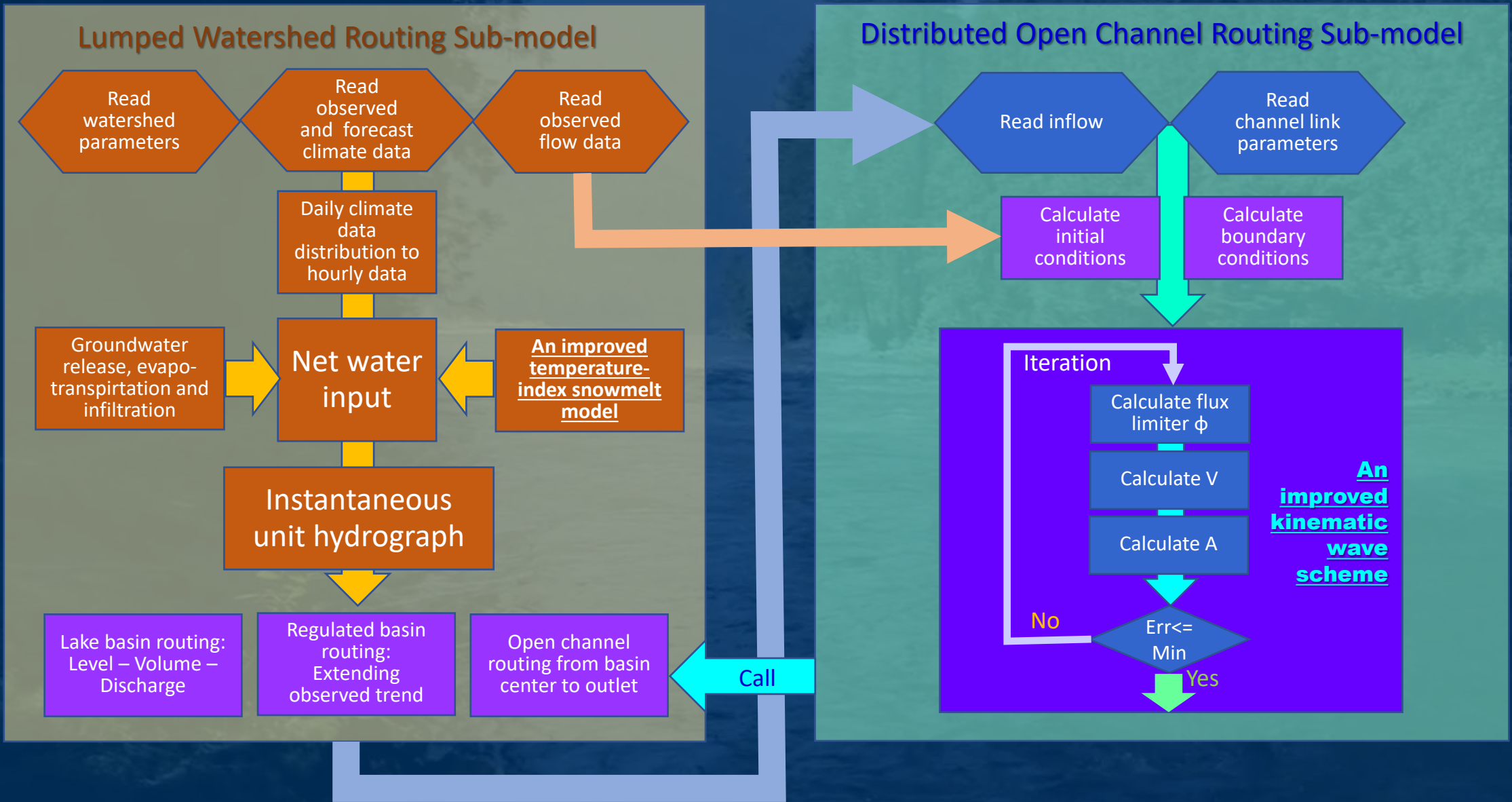


## 2. Model structure – Open channel routing

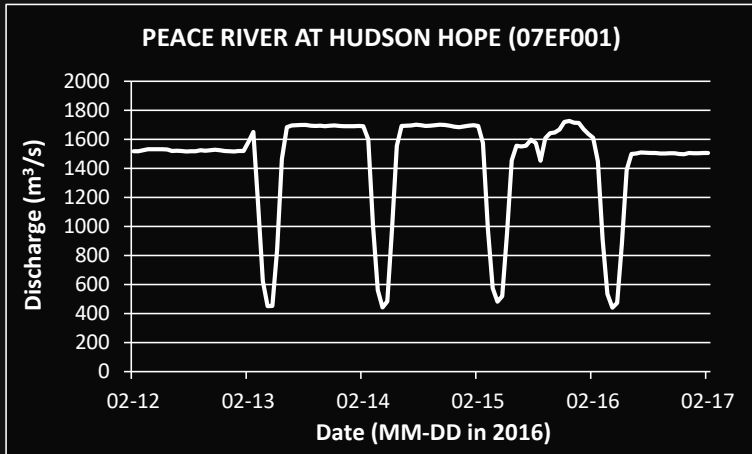




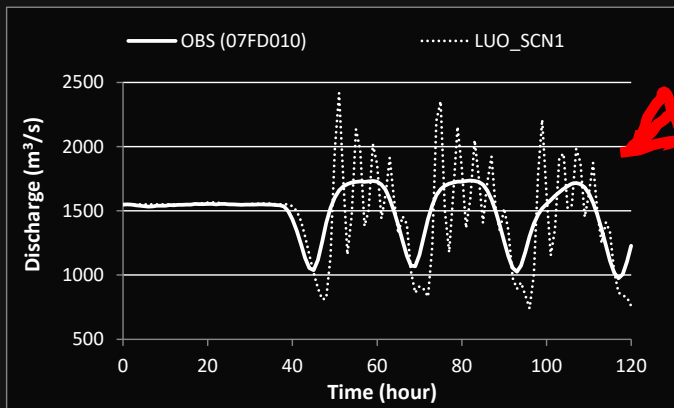
## 2. Model structure – Model flow chart



### 3. Science: Distributed open channel routing — An improved kinematic wave scheme



Highly regulated hydrograph



*Kinematic wave of Saint Venant Equation:*

$$\begin{cases} \frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 & Q_{i,j} = V_{i,j}A_{i,j} & V_{i,j} = \frac{1}{n} \sqrt{S_0} R_{i,j}^{2/3} \\ S_0 = \frac{n^2 Q^2}{A^2 R^{4/3}} \end{cases}$$

*Finite difference with the Preissmann scheme:*

$$A_{i,j} = \frac{\Delta t(Q_{i-1,j} + Q_{i-1,j-1} - Q_{i,j-1}) + \Delta x(A_{i,j-1} + A_{i-1,j-1} - A_{i-1,j})}{\Delta t(V_{i,j}) + \Delta x}$$

*V unknown -> Iteration:*

$$(A_{i,j})^{(k)} = \frac{\Delta t(Q_{i-1,j} + Q_{i-1,j-1} - Q_{i,j-1}) + \Delta x(A_{i,j-1} + A_{i-1,j-1} - A_{i-1,j})}{\Delta t(V_{i,j})^{(k-1)} + \Delta x}$$

$$r_{i,j} = \frac{Q_{i-1,j-1} - Q_{i-1,j-2}}{Q_{i-1,j} - Q_{i-1,j-1}} \quad \varphi(r) = \max[0, \min(1, r)] \quad \text{Minmod Flux limiter}$$

$$(A_{i,j})^{(k)} = \frac{\Delta t Q_{i-1,j} + \Delta x A_{i,j-1}}{\Delta t(V_{i,j})^{(k-1)} + \Delta x} + \varphi(r_{ij}) \frac{\Delta t(Q_{i-1,j-1} - Q_{i,j-1}) + \Delta x(A_{i-1,j-1} - A_{i-1,j})}{\Delta t(V_{i,j})^{(k-1)} + \Delta x}$$



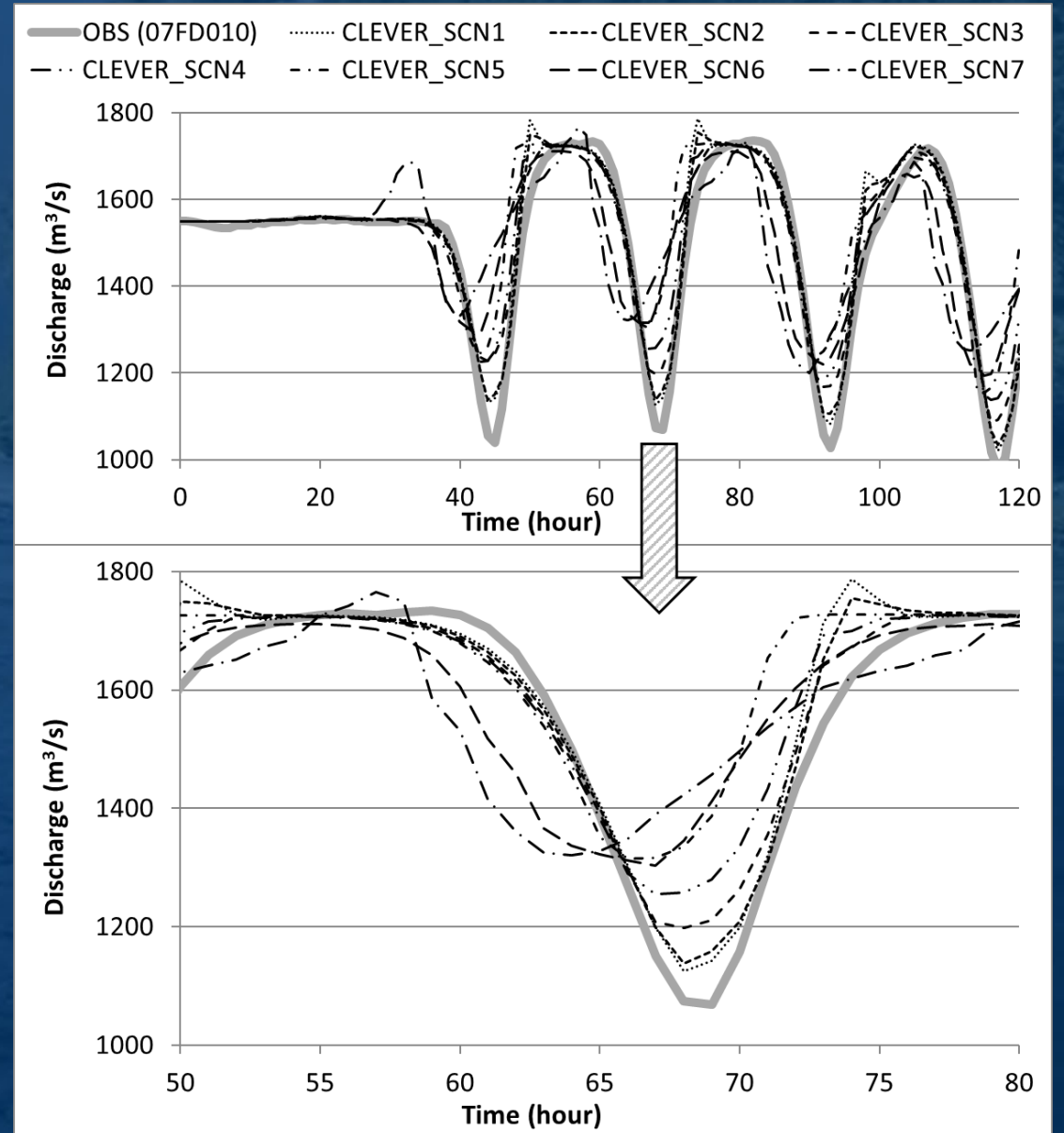
### 3. Science: Distributed open channel routing — An improved kinematic wave scheme

Luo, C. 2021. Comparing Five Kinematic Wave Schemes for Open-Channel Routing for Wide-Tooth-Comb-Wave Hydrographs. Journal of Hydrologic Engineering, ASCE, 26 (4).

**Table 2.** Basic scenarios

River length (km)	$\Delta x$ (km)	$\Delta t$ (s)	$\Delta x/\Delta t$ (m/s)	River segments	Scenario
150	1	3,600	0.278	150	SCN1
150	2.5	3,600	0.694	60	SCN2
150	5	3,600	1.389	30	SCN3
150	7.5	3,600	2.083	20	SCN4
150	10	3,600	2.778	15	SCN5
150	25	3,600	6.944	6	SCN6
150	50	3,600	13.889	3	SCN7

Note:  $\Delta t = 1 \text{ h} = 3,600 \text{ s}$ .





# 4. Science: Lumped watershed routing

– An improved temperature-index snowmelt model



A forest stand



A small basin such as:  
 Kanaka Creek  
 A=49 km<sup>2</sup>

Water balance equation:  

$$W = R + M + G - E - I$$

Temperature-index method:  

$$M = M_f(T_i - T_b)$$
  
 M: snowmelt  
 M<sub>f</sub>: melt factor  
 T<sub>i</sub>: air temperature  
 T<sub>b</sub>: base temperature snow starts to melt



$$x=y$$



Simple



Time Efficiency





# 4. Science: Lumped watershed routing

– An improved temperature-index snowmelt model

Large portion of radiation absorbed by vegetation for photosynthesis

Hourly time step shorter than time needs for snow to melt as estimated

*T* usually lags and attenuate in daytime

Energy for melt is nonlinear to *T*

Overestimate slope of rise (steeper)

Underestimate slope of rise (flatter)



Temperature-index on watershed-scale using hourly time step:

$$M = c_a c_d M_f (T_i - T_b)^\beta$$

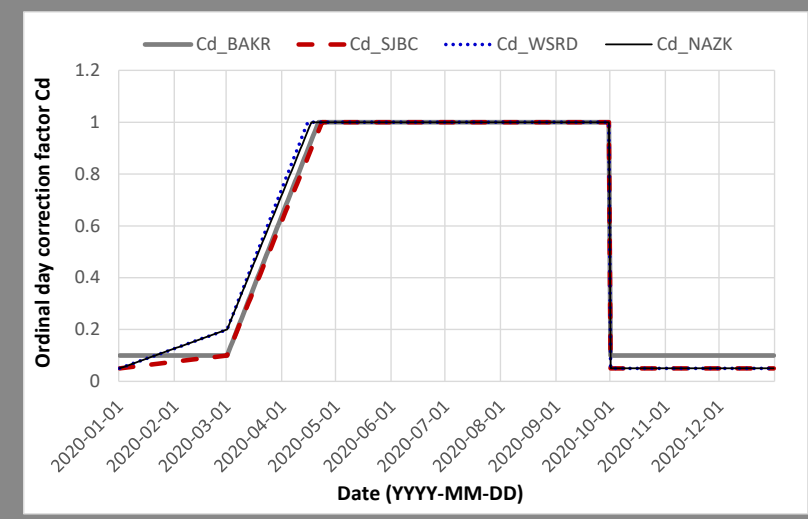
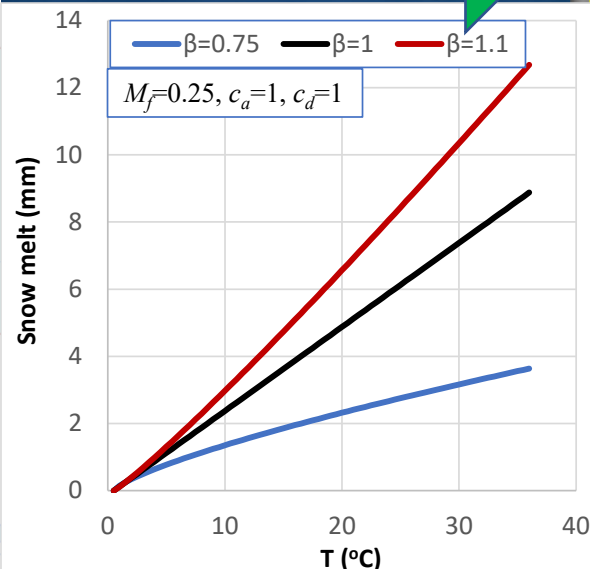
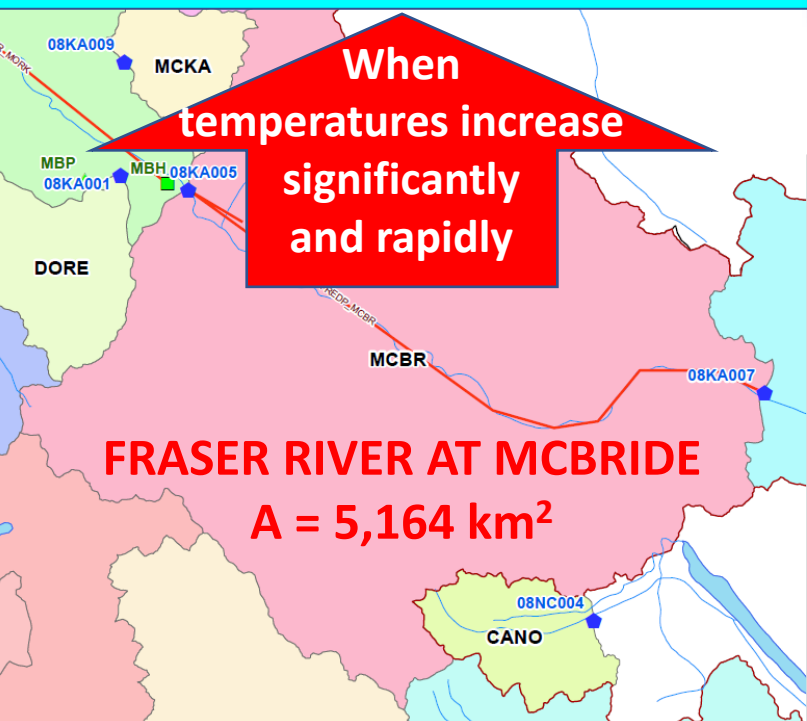
$c_a$ : snow covering correction factor during the snowpack receding period ( $\leq 1$ ):

$$c_a = \left( \frac{SWE_i}{SWE_{max}} \right)^\alpha$$

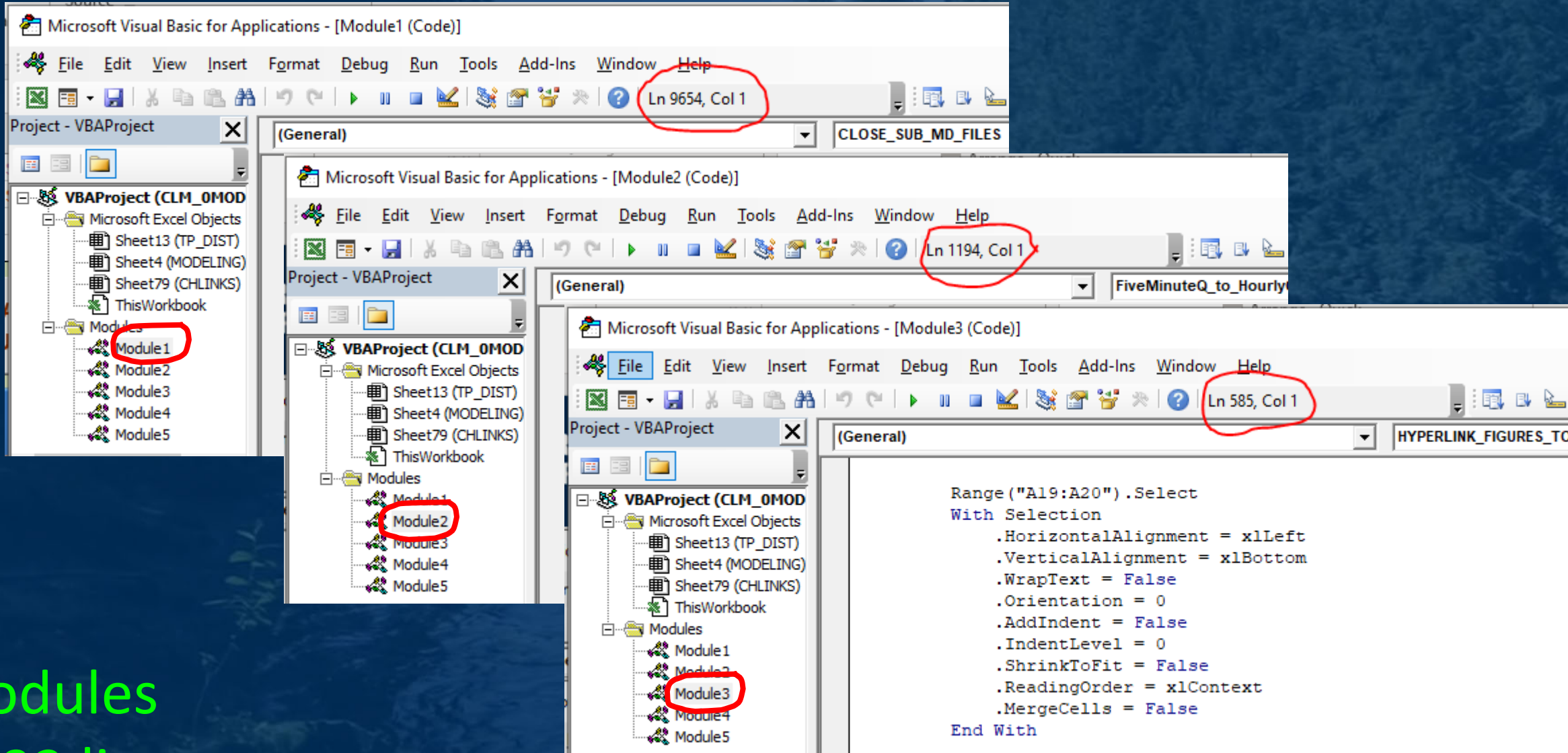
$c_d$ : Ordinal day correction factor ( $\leq 1$ )

$\alpha$ : snowpack covering area receding power

$\beta$ : temperature power, which could be  $>, =, < 1$



# 5. Codes and user interface



Microsoft Visual Basic for Applications - [Module1 (Code)]

File Edit View Insert Format Debug Run Tools Add-Ins Window Help

Ln 9654, Col 1

Project - VBAProject

(General) CLOSE\_SUB\_MD\_FILES

VBAProject (CLM\_0MOD)

- Microsoft Excel Objects
  - Sheet13 (TP\_DIST)
  - Sheet4 (MODELING)
  - Sheet79 (CHLINKS)
  - ThisWorkbook
- Modules
  - Module1
  - Module2
  - Module3
  - Module4
  - Module5

Microsoft Visual Basic for Applications - [Module2 (Code)]

File Edit View Insert Format Debug Run Tools Add-Ins Window Help

Ln 1194, Col 1

Project - VBAProject

(General) FiveMinuteQ\_to\_Hourly

VBAProject (CLM\_0MOD)

- Microsoft Excel Objects
  - Sheet13 (TP\_DIST)
  - Sheet4 (MODELING)
  - Sheet79 (CHLINKS)
  - ThisWorkbook
- Modules
  - Module1
  - Module2
  - Module3
  - Module4
  - Module5

Microsoft Visual Basic for Applications - [Module3 (Code)]

File Edit View Insert Format Debug Run Tools Add-Ins Window Help

Ln 585, Col 1

Project - VBAProject

(General) HYPERLINK\_FIGURES\_TO

VBAProject (CLM\_0MOD)

- Microsoft Excel Objects
  - Sheet13 (TP\_DIST)
  - Sheet4 (MODELING)
  - Sheet79 (CHLINKS)
  - ThisWorkbook
- Modules
  - Module1
  - Module2
  - Module3
  - Module4
  - Module5

```
Range("A19:A20").Select
With Selection
    .HorizontalAlignment = xlLeft
    .VerticalAlignment = xlBottom
    .WrapText = False
    .Orientation = 0
    .AddIndent = False
    .IndentLevel = 0
    .ShrinkToFit = False
    .ReadingOrder = xlContext
    .MergeCells = False
End With
```

5 modules  
12,492 lines



# 5. Codes and user interfaces



AutoSave  Off
CLM\_0MODEL.xlsm - Excel
Luo, Charles FLNR:EX

File Home Insert Page Layout Formulas Data Review View Developer Help ACROBAT
Share Comments

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U		
1	STARTING DATE	2021-03-31	2021-04-20	FORECAST DAY		FRESHET STARTS ON:			01-01					MODEL RUN ON:	2021-04-20				The following buttons are for running on C drive only:  Copy input data files from G drive if running on C drive  Backup Sub-Model files to G drive if running on C drive				
2	ENDING DATE	2021-04-29	2021-04-20	TODAY		FORECAST STARTS ON:			01-21					SIMULATED FM:	2021-03-31								
3	NO SIM/FOR DAYS	30	10											SIMULATED TO:	2021-04-29								
4	INPUT PATH	INPUT\												METHODOLOGY AND MACROS DEVELOPED BY: <b>DR. CHARLES LUO, P.ENG.</b> BC RIVER FORECAST CENTRE, JUNE 2013									
5	OBS CLIMATE DATA	CLIMATE_OBS.xlsx																					
6	FOR CLIMATE DATA	CLIMATE_FOR.xlsx																					
7	OBS FLOW DATA	DISCHARGE_OBS.xlsx																					
8	OBS FLOW DATA HR	DISCHARGE_OBS_HOUR.xlsx																					
9	OUTPUT PATH	OUTPUT\																					
10	CALIBRATION PATH	CALIB\		0/ALL																			
11			OPEN	1-1FRASER																	FORECASTING		
12			SUB-MD	2-2NTWEST																	DEMO ONLY		
13				3-3NTEAST																	FORECASTING		
14			CLOSE	4-4STINTE																	MSGB		
15			SUB-MD	5-5STC VI																	NO MSGB		
16	WATERSHEDS	311		ALL																	MSGB		
17		1	REDP	08KA007	1FRASER									191	CHANNEL LINKS								
18		2	MCBR	08KA005	1FRASER									REDP MCBR	1	1FRASER							
19		3	DORE	08KA001	1FRASER									MCBR MORK	2	1FRASER							
20		4	MCKA	08KA009	1FRASER									MORK FRTP	3	1FRASER							
21		5	MORK	08KA013	1FRASER									FRTP BOHA	4	1FRASER							
22		6	FRTP	99FK004	1FRASER									BOHN BOHA	5	1FRASER							
23		7	TORP	99FK003	1FRASER									BOHA HANS	6	1FRASER							
24		8	BOWR	08KD007	1FRASER									HANS HAMG	7	1FRASER							
25		9	HANS	08KA004	1FRASER									HAMG HAMG	8	1FRASER							
26		10	MGRE	08KB003	1FRASER									HAMG SMPG	9	1FRASER							
27		11	WLLW	08KD00R	1FRASER									SMPG SHEL	10	1FRASER							
28		12	SMPG	08KC001	1FRASER									NBCF NTLY	11	1FRASER							
29		13	SHEL	08KB001	1FRASER									NTLY NVDH	12	1FRASER							
30		14	NBCF	08JA017	1FRASER									NVDH VDST	13	1FRASER							
31		15	STEL	08JB002	1FRASER									STUA VDST	14	1FRASER							
32		16	NTLY	08JB003	1FRASER									VDST NECH	15	1FRASER							
33		17	NVDH	08JC001	1FRASER									NECH CHLA	16	1FRASER							
34		18	DRIF	08JD006	1FRASER									CHLA BSFG	17	1FRASER							
35		19	TSIL	08JE004	1FRASER									SHEL BSFG	18	1FRASER							
36		20	STUA	08JE001	1FRASER									BSFG SFGE	19	1FRASER							
		21	NECH	08JC002	1FRASER									SFGE WSRD	20	1FRASER							
														NAZK WSRN	21	1FRASER							

RUN THE CLEVER MODEL

(WATERSHED & CHANNEL ROUTING)

WATERSHED ROUTING ONLY

CHANNEL ROUTING ONLY

UPDATE DISCHARGE DATA ONLY

EXPORT CALIBRATION

EXPORT FORECAST

SAVE WATERSHED PARAMETERS TO: CLM\_PARAM\_1-1FRASER\_2021-04-20.xlsx

RESTORE WATERSHED PARAMETERS FM: CLM\_PARAM\_1-1FRASER\_2021-04-20.xlsx

Default path: "CALIB\"

↑ PATH (blank if on "CALIB")

Posting clever, clever1, clever2, and clever3 to PROD server: \\answer.bcgov\envwww\rfc\, which is mapped as R drive (about 8 minutes)

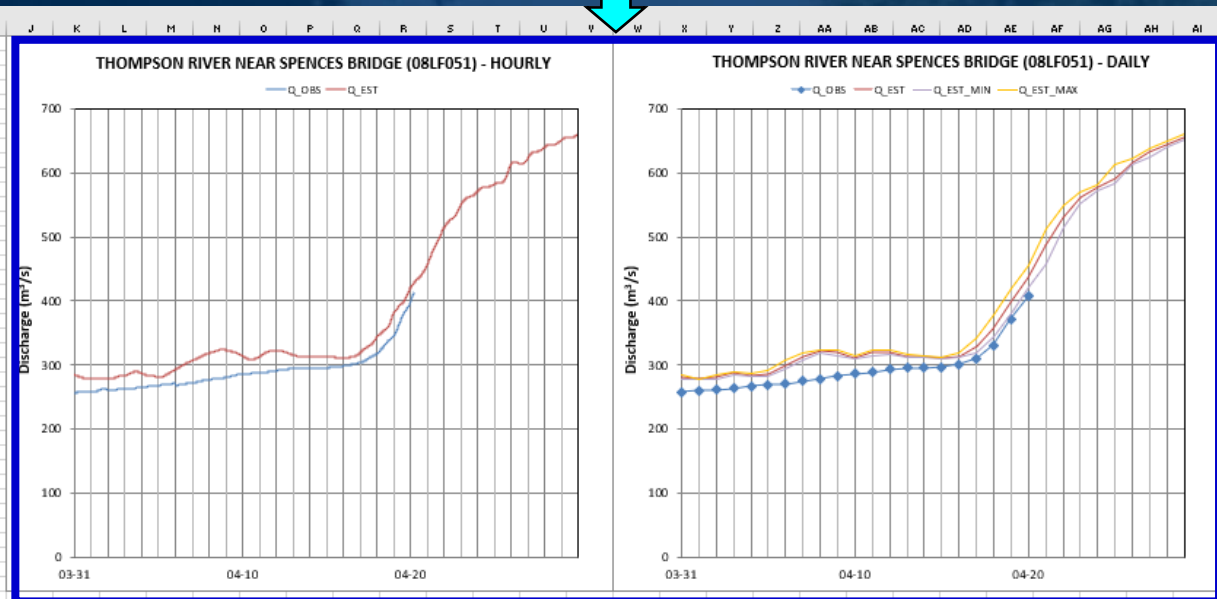
Posting clever only to PROD server: \\answer.bcgov\envwww\rfc\, which is mapped as R drive (about 2 minutes)

Model control interface

Watershed parameter panel

Hydrograph area

AREA (km <sup>2</sup> )	2101	08LF051 - DAILY	WATERSHED TYPE	Natural				
AVERAGE ELEVATION (m)	1000	08LF051 - HOURLY						
STORAGE CONSTANT	3.20	CALCULATED FROM AREA AND FACTOR: 0.2 * 15						
OR TO STORAGE CONSTANT	1.20	CHANGE SHAPE OF HYDROGRAPH, GREATER FLATTER						
HYDROGRAPH CONSTANT	1.00	CHANGE PEAK OF HYDROGRAPH, GREATER, HIGHER						
ST FLOW (C)/PEAK SHIFT (h)	10	0	1	1-RUN GROUNDWATER MODEL				
BASE FLOW (m <sup>3</sup> /s)	0	0	1	INITIAL GW STORAGE (mm)				
OIL MOISTURE DEFICIT (mm)	0.00	2000	MAX GW STORAGE (mm)					
INFILTRATION RATE (mm/h)	0.30	2000	GW RELEASE THRESHOLD (m <sup>3</sup> /h)					
POTRANSPIRATION (mm/h)	0.10	0.05	RATE OF RELEASING (1/HOUR)					
SNOWMELT RATE (mm/C/h)	0.120	0.050	0.100	MELT COEF CHM1, CHM2 (MAR/APR)				
LOW MET/LA RECESS POWER	0.65	0.100	05-01	DATE OF STEADY SNOWMELT				
NUMBER OF CLIMATE STATIONS		ID	WEIGHT	EL (m)	4TR_C	4TR_C_4P	mm	P_Factor
		MNK	0.3	1123	0.0	0.0	-3.0	0.30
		SPK	0.3	972	0.0	0.0	-3.0	0.30
		LTL	0.3	1163	0.0	0.0	-3.0	0.30
		SKO	0.2	1557	0.0	0.0	-3.0	0.30
ROTO MODEL FILE								
ROTO FIGURES SHEET								
		NEW	OLD					
INITIAL SWE (mm)	80	80						
METHOD OF EXTENDING TO 10 DAY FORECAST		1	0.0	0.0	0.0			
STATIC (TRP AS LAST DAY)/2 - STATIC (TRP AS 1-THIS STN ONLY								
FLAT WITH INCREMENT AS SET								
LINEAR WITH UNIFORM SLOPE								
RIVER ROUTING METHOD		1	(1-CHANNEL, 2-LAKE)					
FLOW GAUGE ELEVATION (m)	250							
WNCFFMWSH CENTRE (Km)	57							
SLOPE (S0)	0.013153							
MAHNING ROUGHNESS (N)	0.12							
RIVER WIDTH (m)	100							
TOTAL NUMBER OF 4R	3							
TOTAL NUMBER OF 4T	720							



DATE	HOURLY	Q_OBS	Q_EST	Q_EST_MIN	Q_EST_MAX	DATE	Q_OBS	Q_EST	Q_EST_MIN	Q_EST_MAX		
03-31	1	257	1986	0.098	283.09	1575	285.076	03-31	258.212	280.584	277.868	285.076
	2	257	1982	0.098	282.368	1573	284.35	04-01	260.503	278.005	277.769	278.192
	3	257	1977	0.098	282.04	1572	283.991	04-02	261.465	281.081	278.134	283.991
	4	257	1972	0.098	281.726	1571	283.698	04-03	263.941	287.399	284.055	289.508
	5	257.233	1969	0.097	281.342	1569	283.311	04-04	266.302	295.605	281.222	292.347
	6	256	1964	0.097								
	7	256	1961	0.097								
	8	256	1955	0.097								
	9	256	1949	0.097								
	10	256	1944	0.097								
	11	256	1938	0.096								
	12	256	1933	0.096								
	13	256	193	0.096								
	14	256	1928	0.096								
	15	256.75	1925	0.096								
	16	256	1922	0.096								
	17	256	192	0.096								
	18	256	1910	0.096	276.707	1554	276.625	04-17	269.955	329.296	319.435	342.563
	19	256	1916	0.096	276.526	1553	276.442	04-18	271.022	327.022	318.177	341.737
	20	256	1914	0.096	276.399	1553	276.304	04-19	271.656	327.432	318.177	341.737
	21	256	1913	0.096	276.241	1552	276.154	04-20	270.103	326.444	317.166	340.572
	22	256	1912	0.096	276.127	1552	276.039	04-21	268.573	325.909	316.159	339.169
	23	256	191	0.096	276.019	1552	275.929	04-22	267.045	325.375	315.152	337.762
	24	256	1908	0.096	275.96	1551	275.868	04-23	265.518	324.841	314.145	336.355
	1	256	1906	0.096	275.911	1551	275.817	04-24	264.991	324.307	313.138	334.948
	2	256	1903	0.095	275.859	1551	275.762	04-25	264.464	323.772	312.131	333.541
	3	256	19	0.095	275.877	1551	275.777	04-26	263.937	323.237	311.124	332.134
	4	256	1997	0.095	275.873	1551	275.777	04-27	263.410	322.702	310.117	330.727
	5	256	1994	0.095	275.875	1551	275.779	04-28	262.883	322.167	309.110	329.320
	6	256	199	0.095	275.883	1551	275.773	04-29	262.356	321.632	308.103	327.913
	7	256	1886	0.095	275.905	1551	275.791					
	8	256	1883	0.095	275.946	1551	275.829					
	9	256.083	188	0.095	276.012	1551	275.892					
	10	260	1878	0.095	276.102	1552	275.98					
	11	260	1876	0.095	276.221	1552	276.097					
	12	260	1874	0.095	276.298	1552	276.172					
	13	260.75	1872	0.095	276.308	1552	276.18					
	14	261.503	187	0.094	276.322	1553	276.192					
	15	262	1869	0.094	276.317	1553	276.186					
	16	262	1866	0.094	276.307	1552	276.175					
	17	262	1863	0.094	276.297	1552	276.165					
	18	262	1865	0.094	276.272	1552	276.137					
	19	262	1861	0.094	276.262	1552	276.123					
	20	262	1859	0.094	276.254	1552	276.113					
	21	262	1855	0.094	276.246	1552	276.101					
	22	262	1853	0.094	276.245	1552	276.098					
	23	261.647	185	0.094	276.245	1552	276.095					
	24	261	1846	0.094	276.26	1552	276.106					
	1	261	1845	0.094	276.289	1552	276.134					
	2	261	1844	0.094	276.342	1553	276.186					
	3	261	1849	0.094	276.422	1553	276.265					
	4	261	1843	0.094	276.527	1553	276.37					
	5	261	1843	0.094	276.64	1554	276.503					
	6	261	1844	0.094	276.836	1554	276.68					
	7	261	1844	0.094	277.069	1555	276.913					
	8	261	1844	0.094	277.377	1556	279.221					
	9	261	1842	0.094	277.731	1557	279.573					
	10	261	184	0.094	278.168	1559	280.008					
	11	261	1835	0.093	278.616	156	280.451					
	12	261	1831	0.093	279.102	1562	280.933					
	13	261.167	1828	0.093	279.558	1563	281.336					
	14	262	1826	0.093	279.998	1565	281.814					
	15	262	1824	0.093	280.375	1564	282.199					
	16	262	1821	0.093	280.722	1567	282.542					
	17	262	1816	0.093	281.074	1569	282.894					
	18	262	1815	0.093	281.396	157	283.211					
	19	262	1813	0.093	281.64	157	283.453					
	20	262	1811	0.093	281.898	1571	283.795					

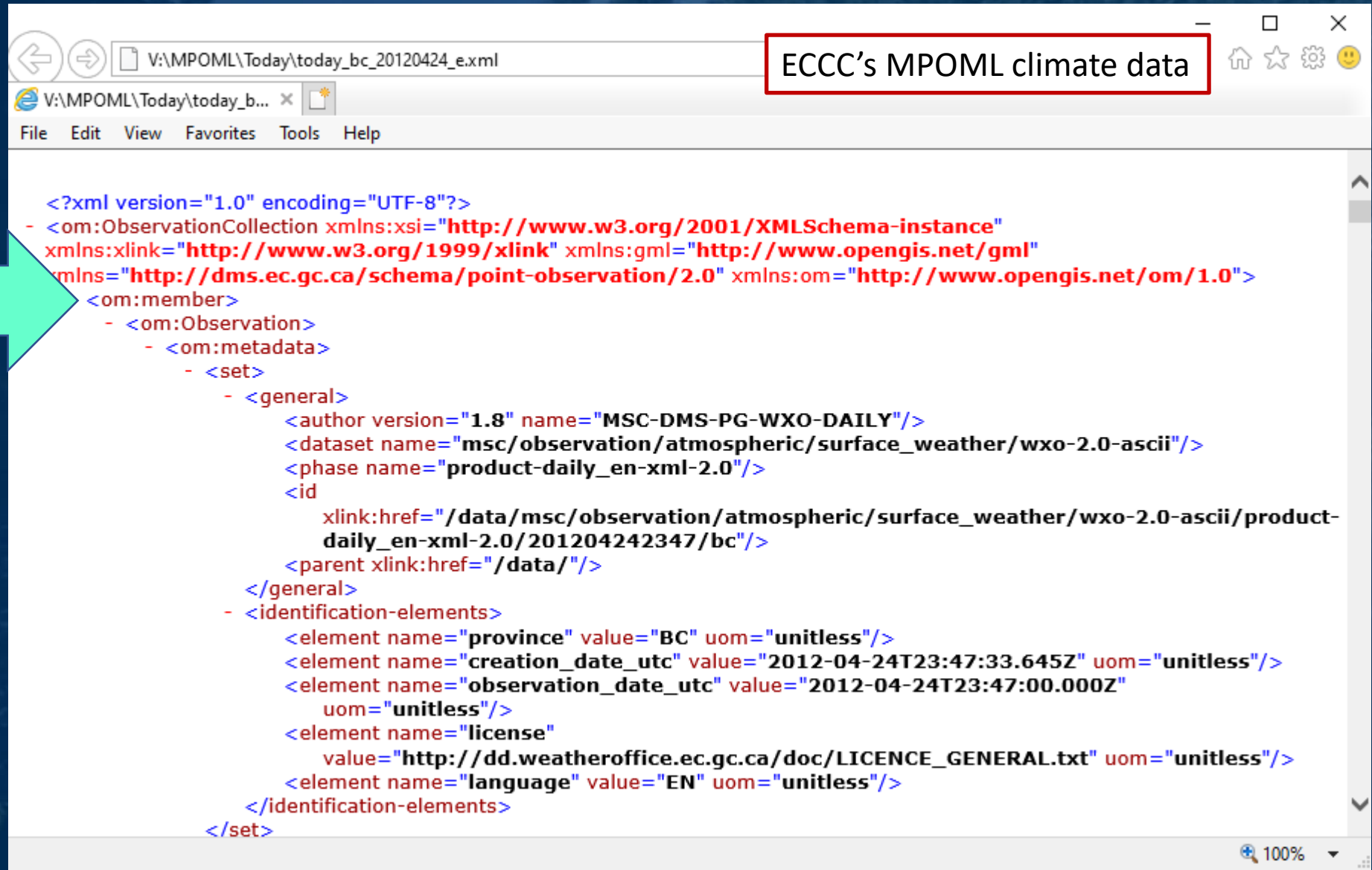
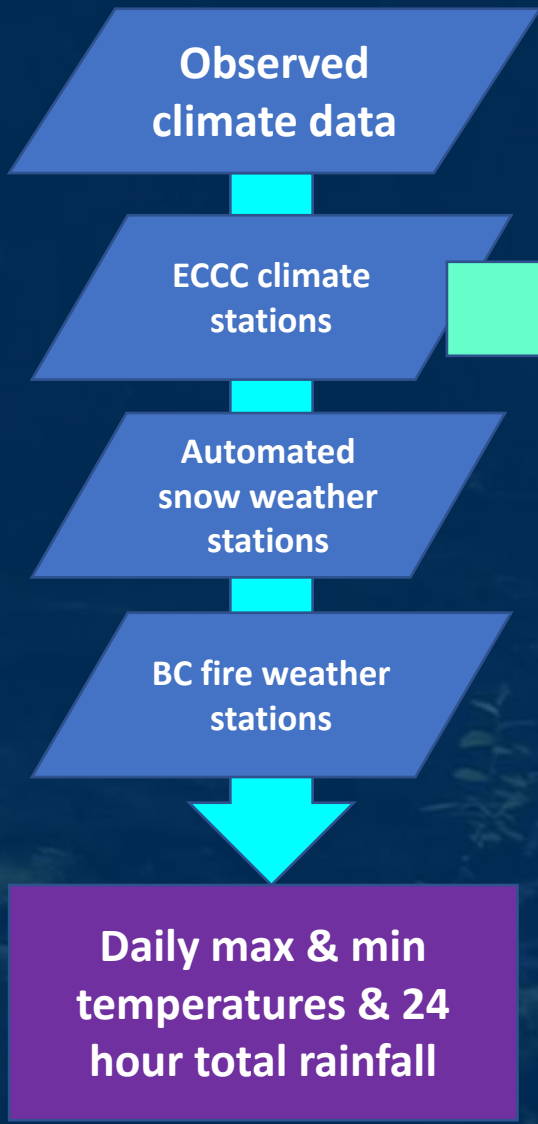
Output data recording area

Input data recording area

Watershed interface



## 6. Input data and data assimilation



```
<?xml version="1.0" encoding="UTF-8"?>
- <om:ObservationCollection xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:gml="http://www.opengis.net/gml"
  xmlns="http://dms.ec.gc.ca/schema/point-observation/2.0" xmlns:om="http://www.opengis.net/om/1.0">
  <om:member>
  - <om:Observation>
    - <om:metadata>
      - <set>
        - <general>
          <author version="1.8" name="MSC-DMS-PG-WXO-DAILY"/>
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          <element name="language" value="EN" uom="unitless"/>
        </identification-elements>
      </set>
    </om:metadata>
  </om:Observation>
  </om:member>
</om:ObservationCollection>
```

# 6. Input data and data assimilation

Forecast climate data

Canadian Meteorological Centre's (CMC) Numerical Weather Prediction (NWP) - GRIB2 format

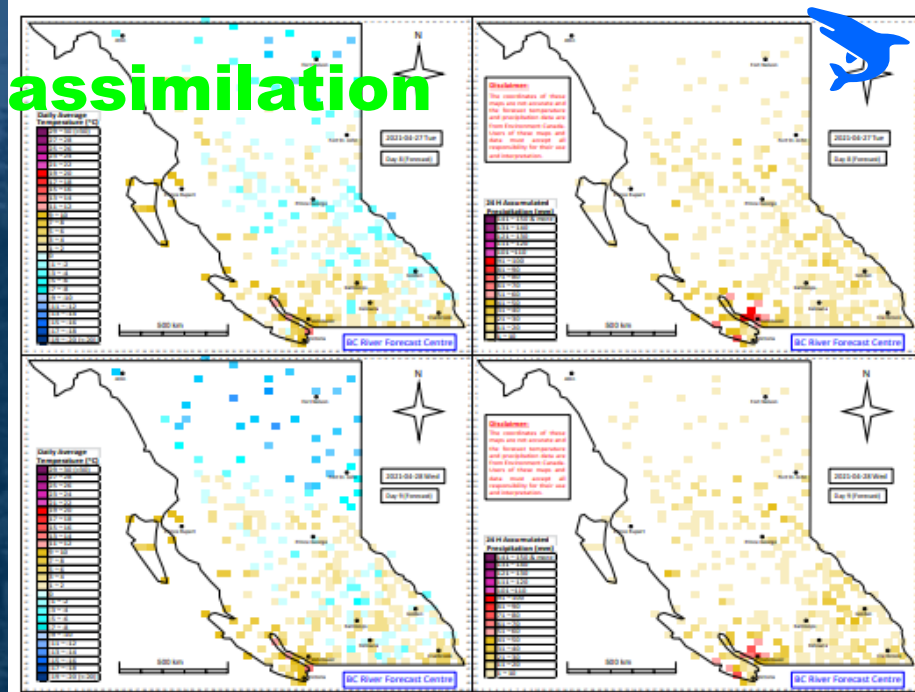
Regional Deterministic Prediction System - RDPS (dx=10 km, dt=3h, Time=0 to 62h)

Global Deterministic Prediction System - GDPS (dx= 25 km, dt =3h, Time used= 63 to 240h)

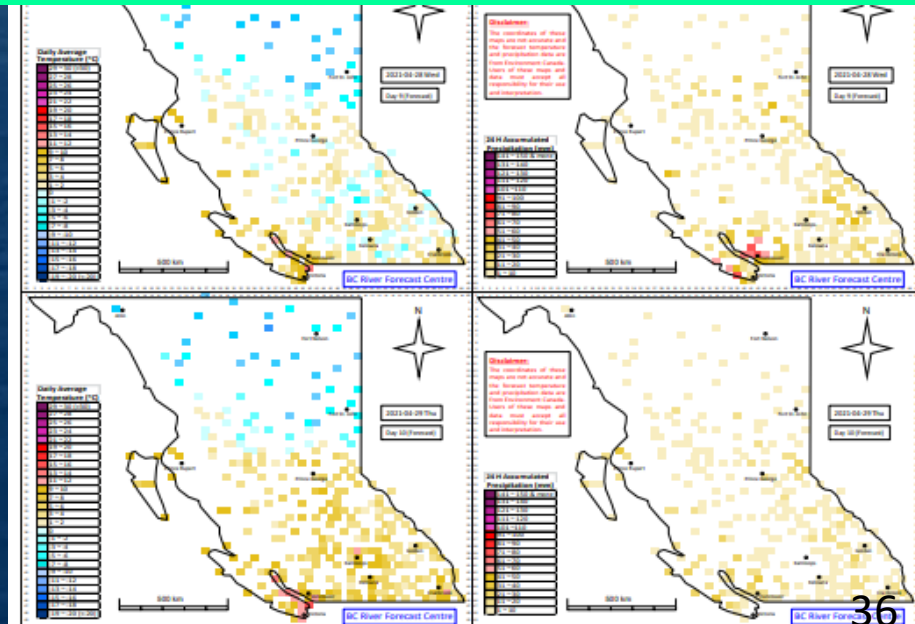
161 files to download (about 20 minutes)

Downscale to

Locations of 368 climate stations (about 20 minutes)



Map of CMC's 10 forecasts of daily average T and daily P [http://bcrfc.env.gov.bc.ca/freshet/FORECAST\\_CMC\\_MAP.pdf](http://bcrfc.env.gov.bc.ca/freshet/FORECAST_CMC_MAP.pdf)





# 6. Input data and data assimilation



Observed Hydrometric data

Water Survey of Canadian DataMart hydrometric data

Hourly + Daily

	A	B	C	PB	PC	PD		A	B	C	IK	IL	IM	IN	IO	IP
1				08PA012	08MB012	10AA001	1				08NA002	08NA006	08NA011	08NB005	08NB017	08NB019
25345			55	8.28	38.6		25345			55	31.4	7.67	5.4	44.2		
25346	03-30	0	0	8.39	38.7	65	25346	03-30	0	0	31.4	0	5.4	37.7		
25347			5	8.24	39.1		25347			5	31.4	0	5.37	44.2		
25348			10	8.13	39.1		25348			10	31.4	7.7	5.37	44.2		
25349			15	8.43	38.3	65	25349			15	31.4	0	5.37	37.7		
25350			20	8.28	39		25350			20	31.4	0	5.37	44.2		
25351			25	8.35	38.8		25351			25	31.4	7.62	5.37	44.2		
25352			30	8.28	39.2	65	25352			30	31.4	7.67	5.35	37.7		
25353			35	8.32	38.7		25353			35	31.4	0	5.35	44.1		
25354			40	8.24	39		25354			40	31.4	0	5.35	44.1		
25355			45	8.28	38.6	65	25355			45	31.3	0	5.32	44		
25356			50	8.35	38.2		25356			50	31.4	7.79	5.32	44		
25357			55	8.43	38.3		25357			55	31.3	7.64	5.32	37.7		
25358	1	0		8.28	38.6	65	25358	1	0		31.3	7.67	5.32	37.7		
25359			5	8.28	37.9		25359			5	31.3	0	5.32	44		
25360			10	8.2	37.6		25360			10	31.3	7.73	5.32	44		
25361			15	8.2	37.2	65	25361			15	31.3	0	5.32	37.7		
25362			20	8.2	37.6		25362			20	31.3	0	5.32	43.9		
25363			25	8.24	37		25363			25	31.3	7.76	5.32	43.9		
25364			30	8.24	38.2	64.9	25364			30	31.3	7.59	5.32	37.7		
25365			35	8.24	38.2		25365			35	31.3	7.73	5.32	43.9		
25366			40	8.2	38.3		25366			40	31.3	0	5.29	43.9		
25367			45	8.17	38.4	64.9	25367			45	31.3	0	5.29	37.7		
25368			50	8.17	38.4		25368			50	31.3	0	5.29	43.9		
25369			55	8.24	37.9		25369			55	31.3	7.62	5.29	43.9		
25370	2	0		8.2	38.4	64.9	25370	2	0		31.3	7.62	5.29	37.7		
25371			5	8.2	38.2		25371			5	31.3	7.73	5.29	43.8		
25372			10	8.02	38		25372			10	31.3	0	5.29	43.8		
25373						64.9	25373			15	31.3	0	5.29	37.7		
25374							25374			20	31.3	7.73	5.29	43.8		
25375							25375			25	31.3	0	5.29	43.8		
25376						64.9	25376			30	31.3	7.56	5.29	37.7		
25377			35	8.13	38.4		25377			35	31.2	7.47	5.29	43.8		
25378			40	8.2	38.4		25378			40	31.3	0	5.29	43.8		
25379			45	8.17	38.7	64.9	25379			45	31.3	0	5.29	37.7		

Different time step

Irregularly missing

Completely missing

## Real-Time Hydrometric Data Graph for MCGREGOR RIVER AT LOWER CANYON (08KB003) [BC]

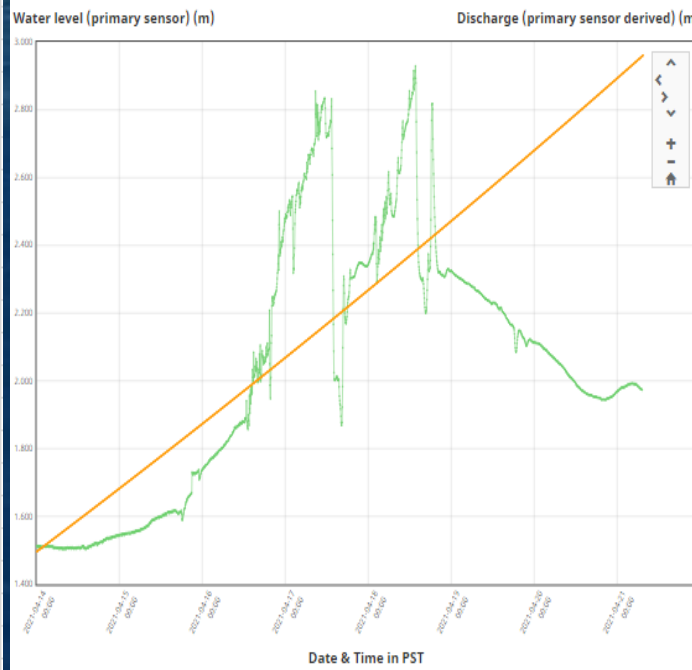
**Station Notice**  
The regular flow measurement program at this hydrometric gauge is compromised because the cableway is currently out of service. Please email ec.shnhydrologiquebc-nhshydrologicalbc.ec@canada.ca with any questions or concerns.

Obviously wrong data

Station: 08KB003 Data Type: Real-Time

Download? Apply

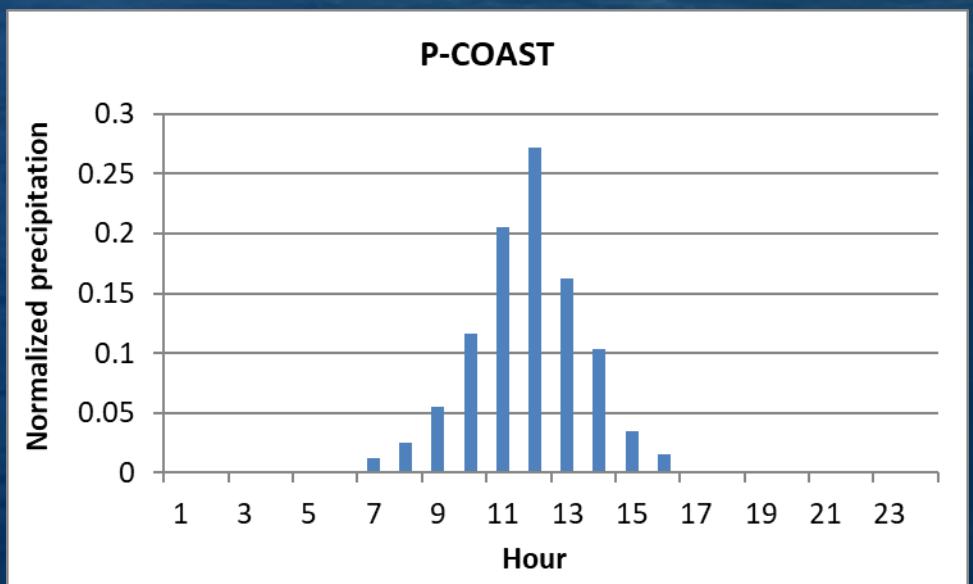
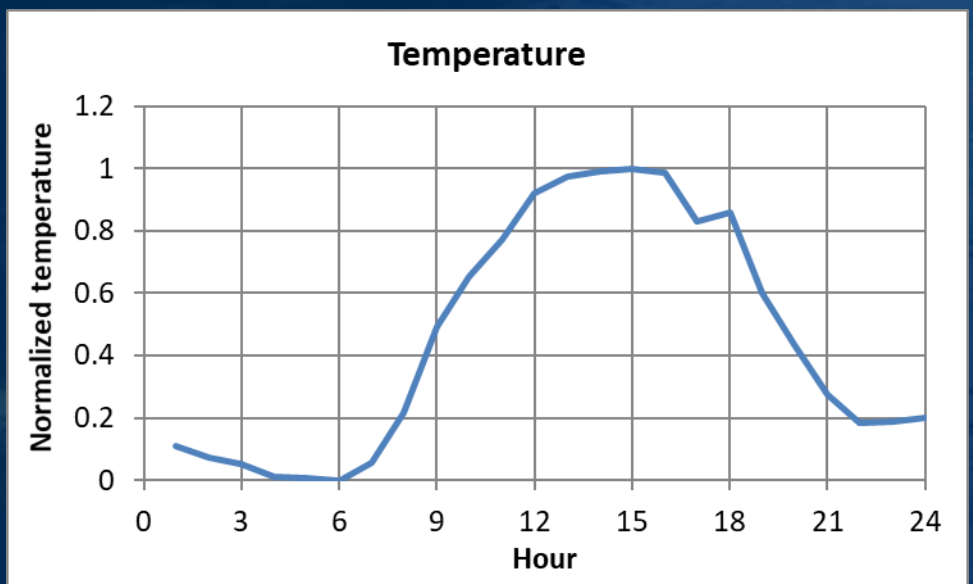
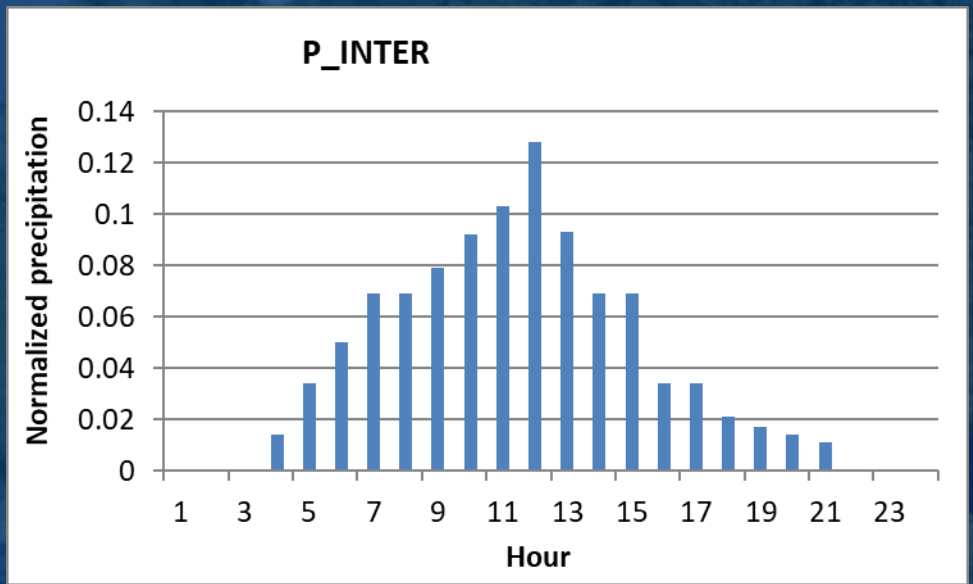
**Legend**  
Water level (primary sensor) - Provisional  
Discharge (primary sensor derived) - Provisional



# 6. Input data and data assimilation



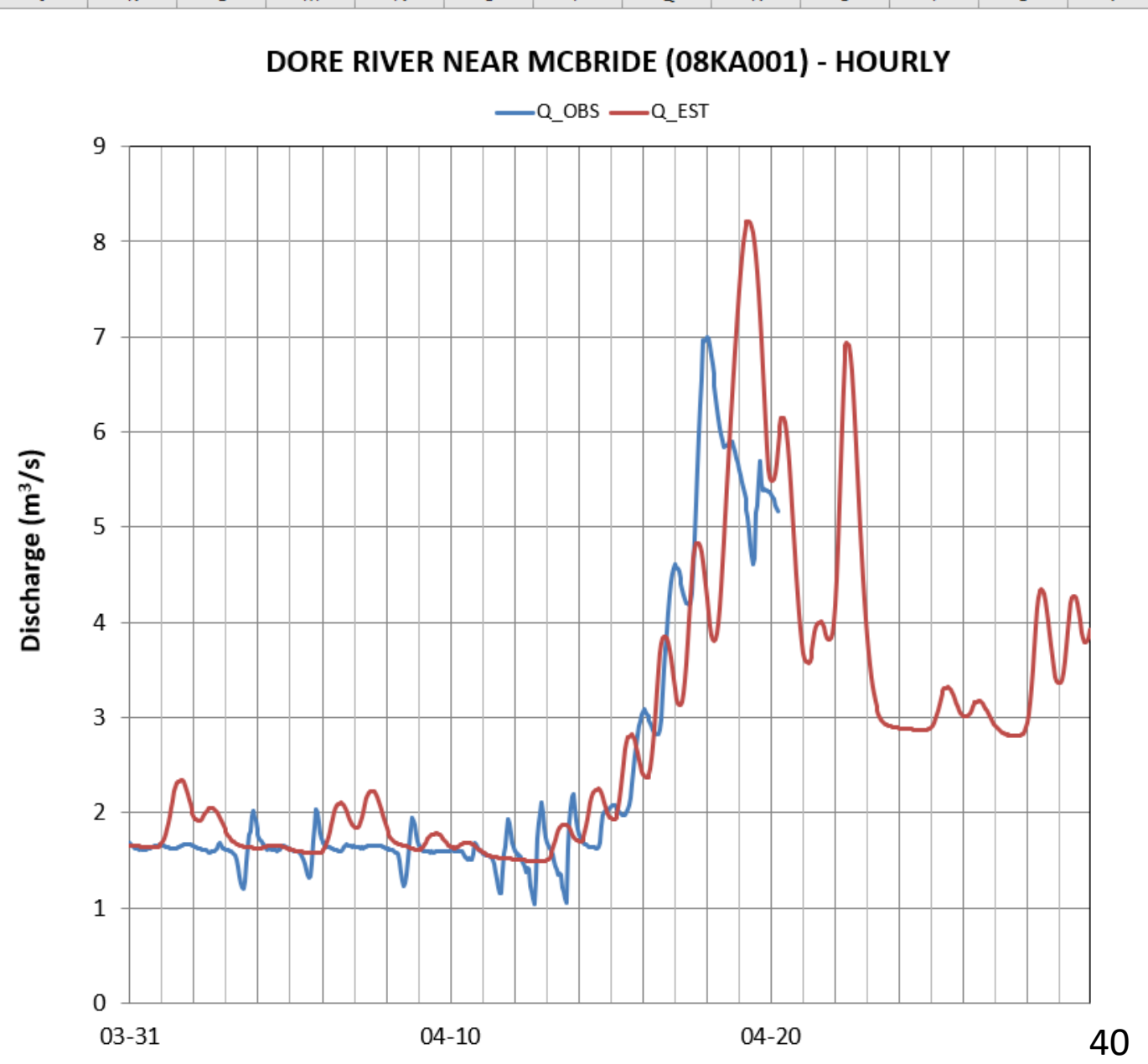
In the model:  
Daily climate data  
are distributed to  
hourly data







	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	WATERSHED	DORE RIVER NEAR MCBRIDE (08KA001)										DORE										
2	AREA (km2)	407	(08KA001) - DAILY										WATERSHED TYPE Natural									
3	AVERAGE ELEVATION (m)	1600	(08KA001) - HOURLY																			
5	STORAGE CONSTANT	2.00	CALCULATED FROM AREA AND FACTOR: 0.2 - 15																			
6	FACTOR TO STORAGE CONSTANT	1.20	CHANGE SHAPE OF HYDROGRAPH, GREATER, FLATTER																			
7	HYDROGRAPH CONSTANT	1.00	CHANGE PEAK OF HYDROGRAPH, GREATER, HIGHER																			
8	FAST FLOW (%) / PEAK SHIFT (%)	1	0	1	1- RUN GROUNDWATER MODEL																	
9	BASE FLOW (m3/s)	0.5	0 INITIAL GW STORAGE (mm)																			
10	SOIL MOISTURE DEFICIT (mm)	0.00	1000 MAX GW STORAGE (mm)																			
11	INFILTRATION RATE (mm/h)	0.40	200 GW RELEASE THRESHOLD (m3/s)																			
12	EVAPOTRANSPIRATION (mm/h)	0.05	0.15 RATE OF RELEASING (1/HOUR)																			
13	SNOWMELT RATE (mm/C/h)	0.360	0.050	0.300	MELT COEF CMD1, CMD2 (MAR/APR)																	
14	SNOW MELT/A RECESS POWER	0.75	0.200	05-21	DATE OF STEADY SNOWMELT																	
15	NUMBER OF CLIMATE STATIONS	ID	WEIGHT	EL (m)	dTX_C	dTN_C	dP_mm	P_factor														
16		2	MBP	0.6	1611	0.0	0.0	-4.0	0.80													
17			MBH	0.4	716	0.0	0.0	-5.0	0.70													
19	<a href="#">&lt;-GO TO MODEL FILE</a>																					
20	<a href="#">&lt;-GO TO FIGURES SHEET</a>																					
21																						
22	INITIAL SWE (mm)	NEW	OLD	UPDATE DISCHARGE DATA ONLY																		
22		1200	1200																			
24	METHOD OF EXTENDING TO 10 DAY FORECAST			1	0.0	0.0	0.0															
25	1 - STATIC (T&P AS LAST DAY) / 2 - STATIC (T&P AS SET)	1-THIS STN ONLY		EXPORT FORECAST FOR THIS WATERSHED																		
26	3 - FLAT WITH INCREMENT AS SET	2-ALL SUB BASINS																				
27	4 - LINEAR WITH UNIFORM SLOPE	3-DOWSTREAM																				
28		4-ENTIRE GROUP		1																		
29	RIVER ROUTING METHOD	1	(1-CHANNEL, 2-LAKE)		ADDITIONAL INFLOWS FOR LAKE																	
30		dX(Km)	dT(s)	dX/dT																		
31		8	3600	2.222																		
32	FLOW GAUGE ELEVATION (m)	750		1 - RE-LOAD																		
33	DISTANCE FM WTSN CENTRE (Km)	16		INPUT FILES																		
34	SLOPE (S0)	0.053335		BLANK(DEFAULT) -																		
35	MANNING ROUGHNESS (N)	0.12		NOT RE-LOAD INPUT FILES																		
36	RIVER WIDTH (m)	40		RE-CALIBRATE THIS WATERSHED																		
37	TOTAL NUMBER OF dX	2		FORECAST BIAS-CORRECTION (%):																		
38	TOTAL NUMBER OF dT	720		Linear Hours																		

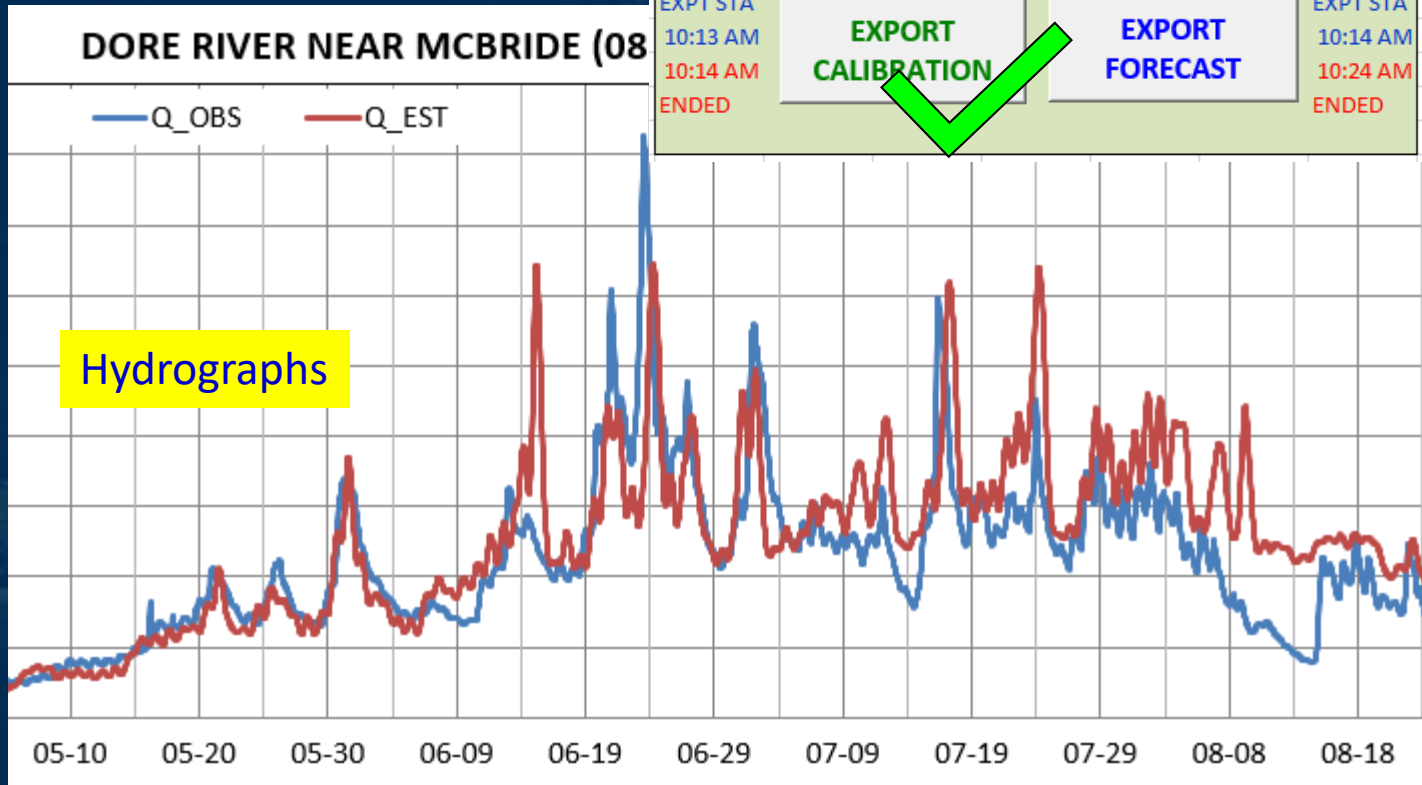
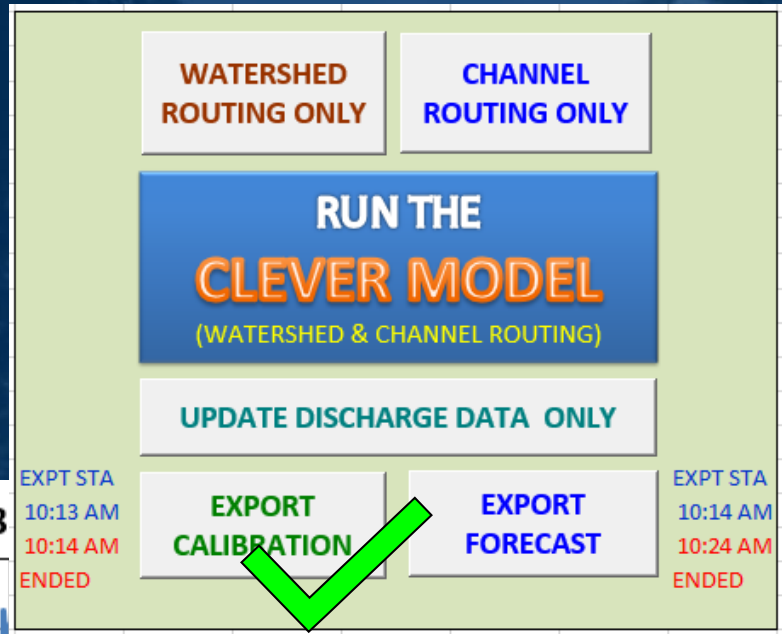


# 7. Model calibration – flexibility to adapt to climate changes



DATE	HOUR	Q_OBS	Q_EST_W	H_EST(m)
01-01	1	3.76	2	0.148
	2	3.76	2	0.148
	3	3.76	2	0.148
	4	3.76	2	0.148
	5	3.76	2	0.148
	6	3.76	2	0.148
	7	3.76	2	0.148
	8	3.76	2	0.148

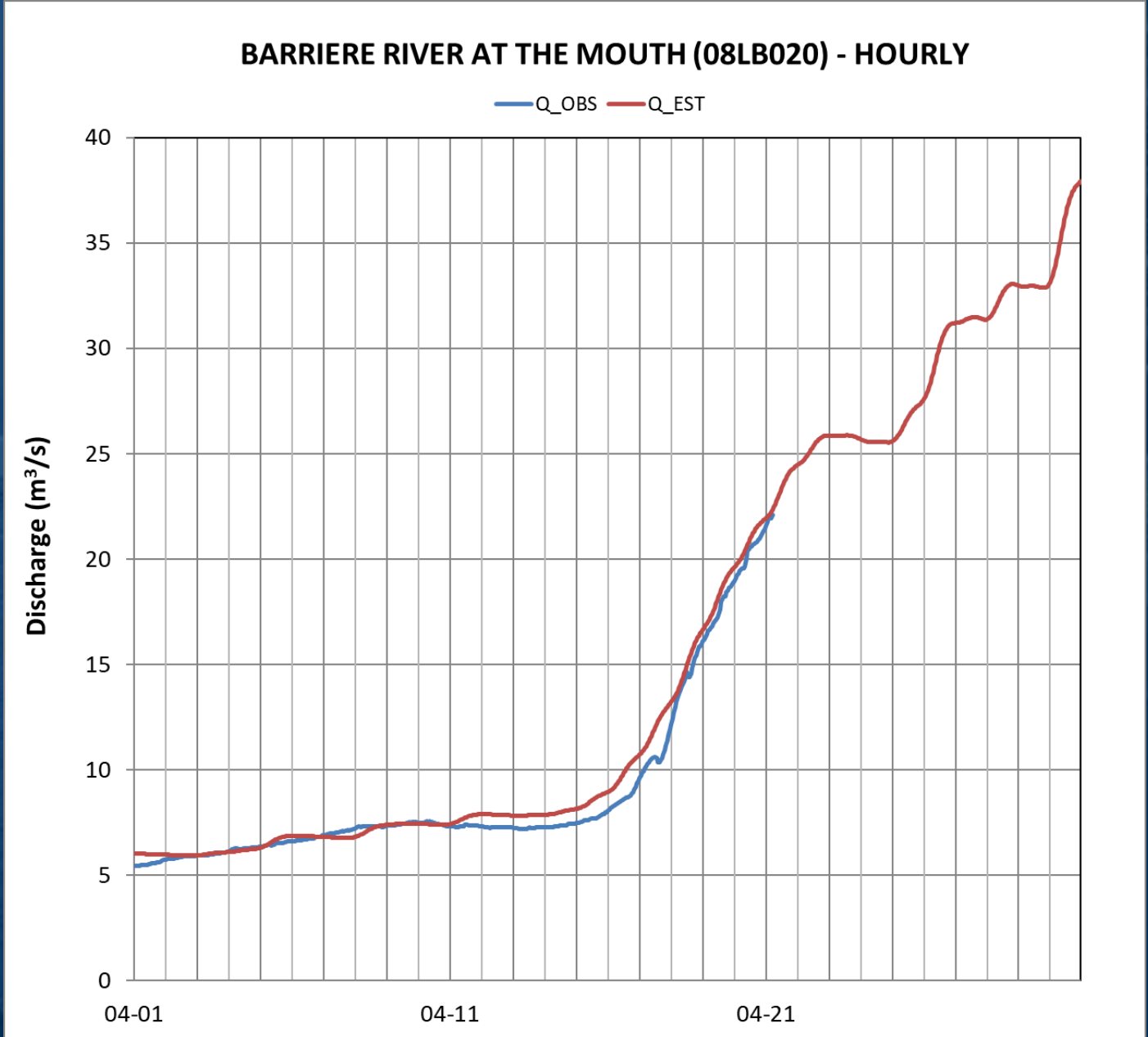
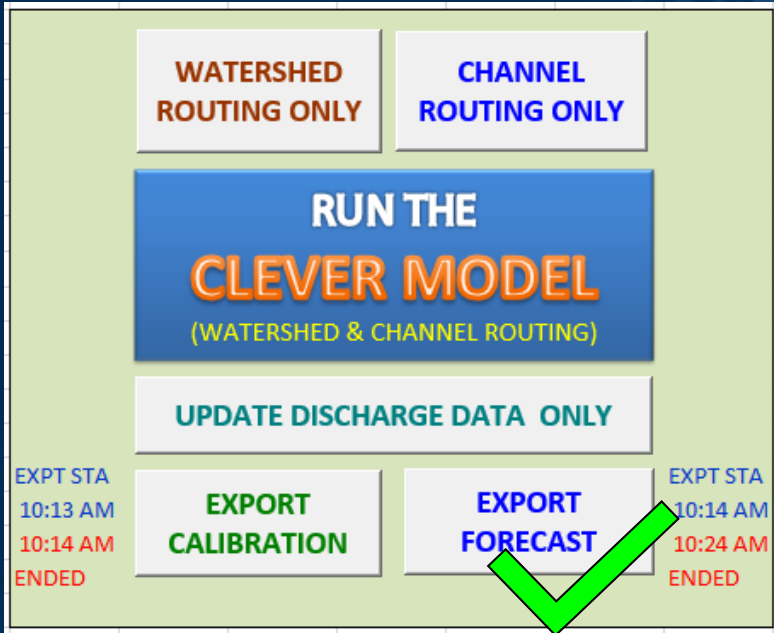
Observed & estimated discharges/water levels



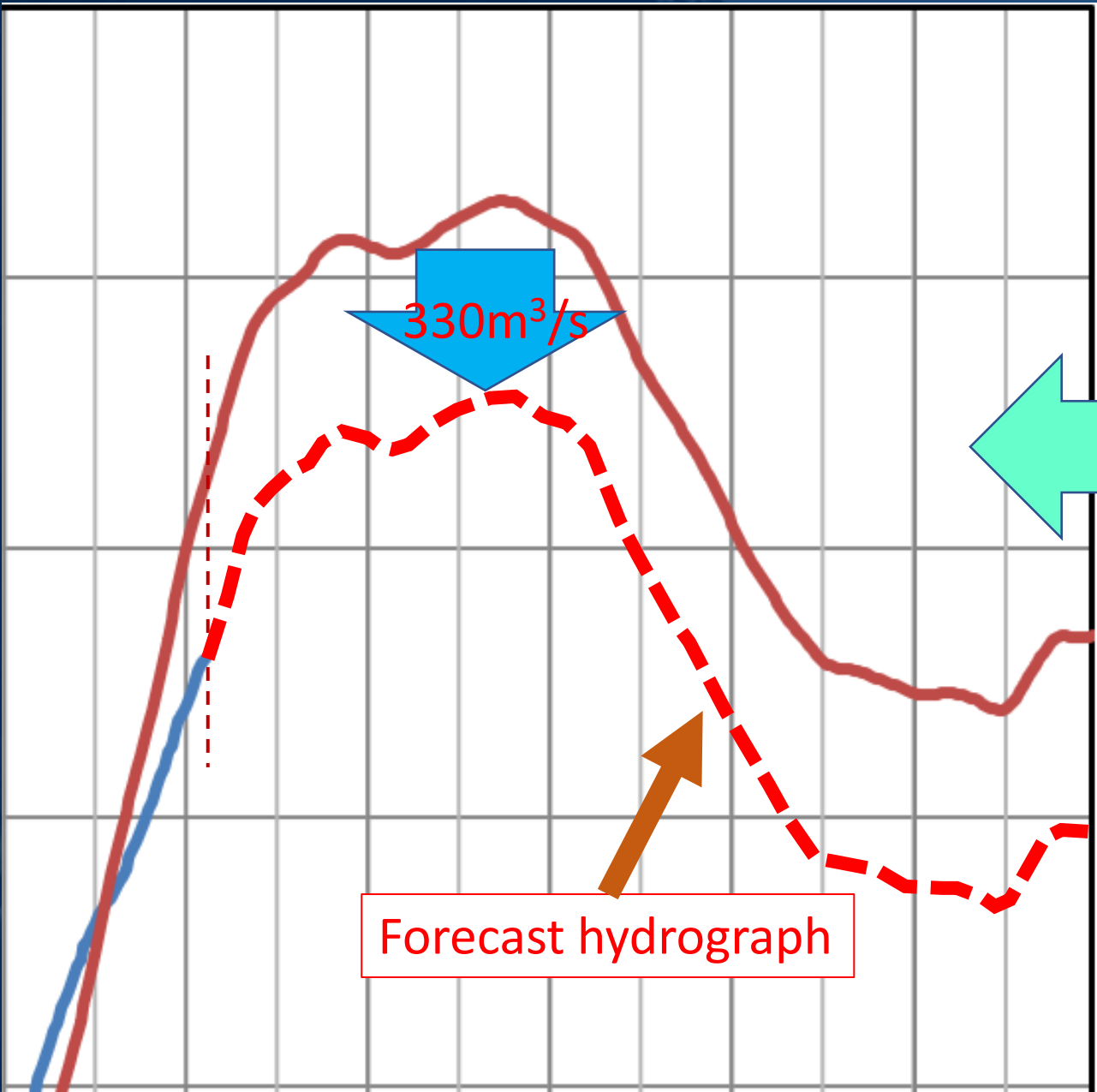
WATERSH DORE RIVER NEAR MCBRIDE (08KA001)		DORE RIVER NEAR MCBRIDE (08KA001) - HOURLY		DORE		
AREA (km <sup>2</sup> )	407	DORE RIVER NEAR MCBRIDE (08KA001) - HOURLY		Natural		
AVERAGE	1600					
STORAGE	2.00	CALCULATED FROM AREA AND FACTOR: 0.2 - 15				
FACTOR T	1.20	CHANGE SHAPE OF HYDROGRAPH, GREATER, FLATTER				
HYDROGR	1.00	CHANGE PEAK OF HYDROGRAPH, GREATER, HIGHER				
FAST FLOW	1	0	1	1- RUN GROUNDWATER MODEL		
BASE FLOW	2	0 INITIAL GW STORAGE (mm)				
SOIL MOIS	0.00	1000	MAX GW STORAGE (mm)			
INFILTRAT	0.40	200	GW RELEASE THRESHOLD (m3/s)			
EVAPOTRA	0.05	0.5 RATE OF RELEASING (1/HOUR)				
SNOWME	0.350	0.050	0.100	MELT COEF CMD1, CMD2 (MAR/APR)		
SNOW ME	0.75	0.200	05-21	DATE OF STEADY SNOWMELT		
NUMBER (ID	WEIGHT	EL (m)	dTX_C	dTN_C	dP_mm	P_factor
2 MBP	0.6	1611	0.0	0.0	-4.0	1.00
MBH	0.4	716	0.0	0.0	-5.0	0.90
<-GO TO MODEL FILE		Model parameters		RAINFALL		1
<-GO TO FIGURES SH						
	NEW	OLD				
INITIAL SV	1200	1200	dTX_C	dTN_C	dP_mm	
METHOD OF EXTENDING TO 10		1	0.0	0.0	0.0	
1 - STATIC (T&P AS LAST DAY)/2		1-THIS STN ONLY				
3 - FLAT WITH INCREMENT AS S		2-ALL SUB BASINS				
4 - LINEAR WITH UNIFORM SLO		3-DOWSTREAM				
		4-ENTIRE GROUP				1
RIVER ROU	1	(1-CHANNEL, 2-LAKE)		ADDITIONAL INFLOWS FOR LAK		
	dx(Km)	dT(s)	dx/dT			
	8	3600	2.222			
FLOW GAU	750	1 - RE-LOAD				
DISTANCE	16	INPUT FILES				
SLOPE (SO	0.053125	BLANK(DEFAULT) -				
MANNING	0.12	NOT RE-LOAD INPUT FILES				
RIVER WID	40					
TOTAL NU	2			FORECAST	100	
TOTAL NU	720			Linear Ho	12	



# 8. Producing forecasts – informative and easy to read



# 8. Producing forecasts – informative and easy to read



FORECAST BIAS-CORRECTION (%)	100
Linear Hours	<del>12</del>





## The Channel Links Evolution Efficient Routing (CLEVER) Model

<i>2013</i>	Planning, researching and coding the first version of the CLEVER Model(M)	32 stn	<i>2018</i>	Operational running the CLEVER Model (High water year)	108 stn
<i>2014</i>	Test running the CLEVER Model (Moderate water year)	51 stn	<i>2019</i>	Providing CSV files of hourly forecast for users to download (Low water y)	119 stn
<i>2015</i>	<u>Starting operational running the CLEVER Model</u> (Low water year)	71 stn	<i>2020</i>	Significant expanding modeling scope (Extensive flooding year)	266 stn
<i>2016</i>	Operational running the CLEVER Model (Very low water year)	74 stn	<i>2021</i>	<ol style="list-style-type: none"> <li>Massive upgrading, including feature allowing multi-users to run the model in parallel to improve time efficiency.</li> <li>First paper about the CLEVER Model published in an international peer reviewed journal (J. Hydro. Eng., ASCE)</li> </ol>	311 stn
<i>2017</i>	Significant increase of modeled stations (Moderate water year)	102 stn			

# 10. Post freshet review of model performance

– statistics and flooding events

## Statistic analysis:

Coefficient of model efficiency ( $C_e$ )

$$C_e = 1 - \frac{\sum_{j=1}^m (Q_{obs}^j - Q_{sim}^j)^2}{\sum_{j=1}^m (Q_{obs}^j - \overline{Q_{obs}})^2}$$

$$\overline{Q_{obs}} = \frac{1}{m} \sum_{j=1}^m Q_{obs}^j$$

$$\overline{Q_{sim}} = \frac{1}{m} \sum_{j=1}^m Q_{sim}^j$$

$$\overline{Q_{sim}^2} = \frac{1}{m} \sum_{j=1}^m (Q_{sim}^j)^2$$

$$\overline{Q_{obs}^2} = \frac{1}{m} \sum_{j=1}^m (Q_{obs}^j)^2$$

## Statistic analysis for model calibration

Coefficient of determination ( $C_d$ )

$$C_d = 1 - \frac{\sum_{j=1}^m [Q_{obs}^j - (a \cdot Q_{sim}^j + b)]^2}{\sum_{j=1}^m (Q_{obs}^j - \overline{Q_{obs}})^2}$$

$$a = (\overline{P} - \overline{Q_{obs}} \cdot \overline{Q_{sim}}) / (\overline{Q_{sim}^2} - \overline{Q_{sim}}^2)$$

$$b = \overline{Q_{obs}} - a \cdot \overline{Q_{sim}}$$

$$\overline{P} = \frac{1}{m} \sum_{j=1}^m (Q_{obs}^j \cdot Q_{sim}^j)$$

Percentage volume difference ( $dV$ )

$$dV = 100 \times (\overline{Q_{sim}} - \overline{Q_{obs}}) / \overline{Q_{obs}}$$

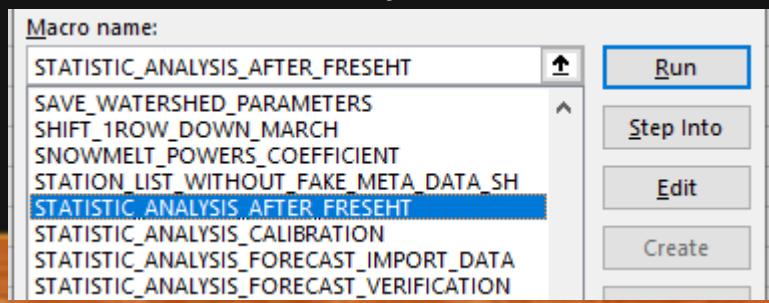
## Statistic analysis for forecasts

Relative mean absolute error ( $E_{ra}$ )

$$E_{ra} = 100 \times \left( \frac{1}{m} \sum_{j=1}^m |Q_{sim}^j - Q_{obs}^j| \right) / \overline{Q_{obs}}$$

r squared ( $r^2$ )

$$r^2 = \frac{[\sum_{j=1}^m (Q_{obs}^j - \overline{Q_{obs}})(Q_{sim}^j - \overline{Q_{sim}})]^2}{\sum_{j=1}^m (Q_{obs}^j - \overline{Q_{obs}})^2 \sum_{j=1}^m (Q_{sim}^j - \overline{Q_{sim}})^2}$$





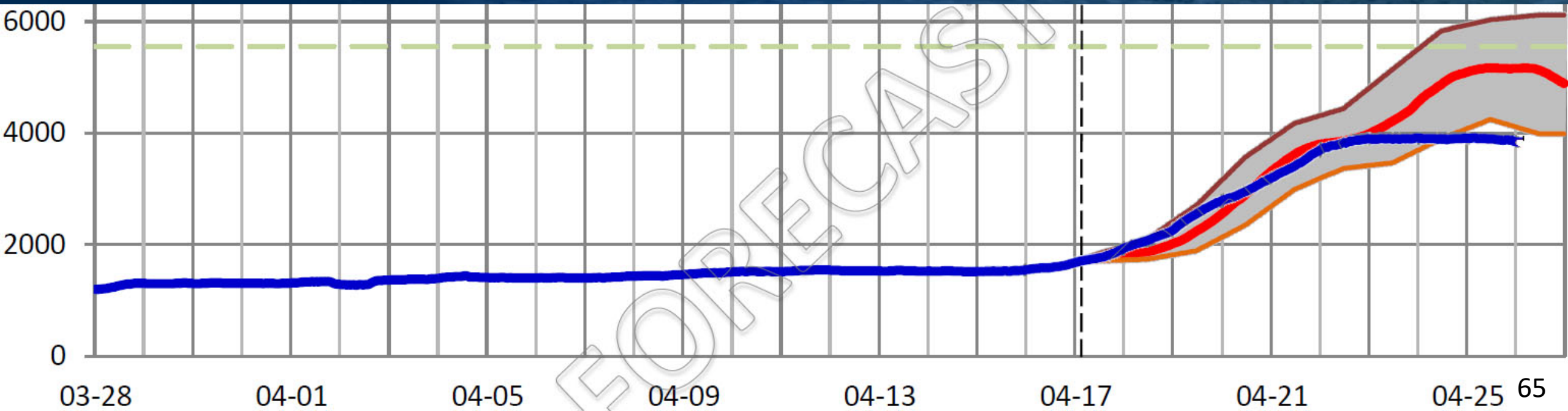
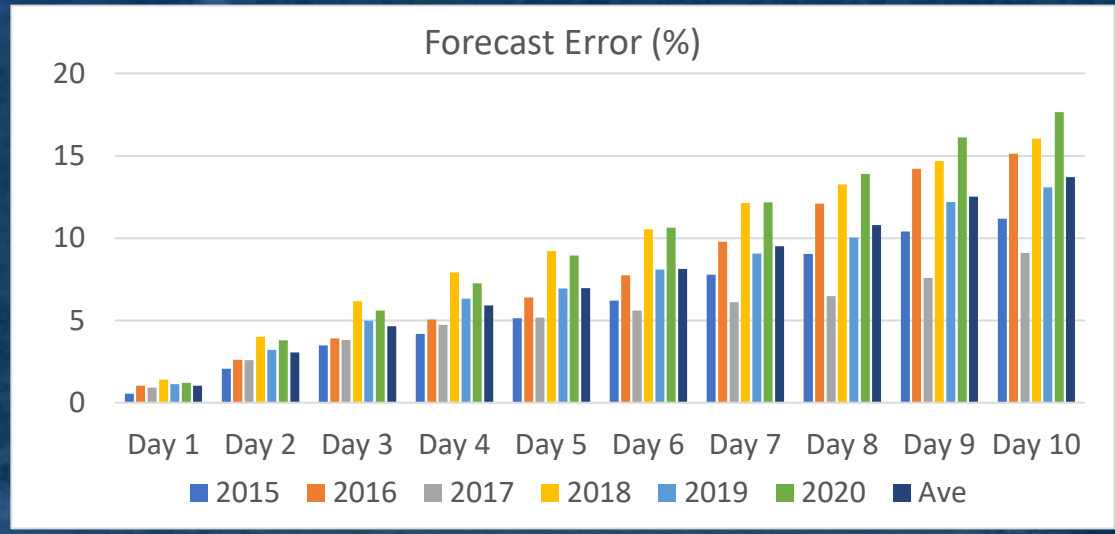


# 10. Post freshet review of model performance

– statistics and flooding events

## Forecast errors of FRASER RIVER AT HOPE (08MF005)

Year	Forecast Error (%)										Statistics	
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	AveErr	RSQU
2015	0.6	2.1	3.5	4.2	5.1	6.2	7.8	9.0	10.4	11.2	6.0	0.738
2016	1.0	2.6	3.9	5.1	6.4	7.7	9.8	12.1	14.2	15.1	7.8	0.444
2017	0.9	2.6	3.8	4.7	5.2	5.6	6.1	6.5	7.6	9.1	5.2	0.772
2018	1.4	4.0	6.2	7.9	9.2	10.5	12.1	13.3	14.7	16.0	9.5	0.606
2019	1.1	3.2	5.0	6.3	6.9	8.1	9.1	10.0	12.2	13.1	7.5	0.554
2020	1.2	3.8	5.6	7.3	8.9	10.6	12.2	13.9	16.1	17.6	9.7	0.497
<b>Ave</b>	<b>1.0</b>	<b>3.0</b>	<b>4.7</b>	<b>5.9</b>	<b>7.0</b>	<b>8.1</b>	<b>9.5</b>	<b>10.8</b>	<b>12.5</b>	<b>13.7</b>	<b>7.6</b>	<b>0.602</b>



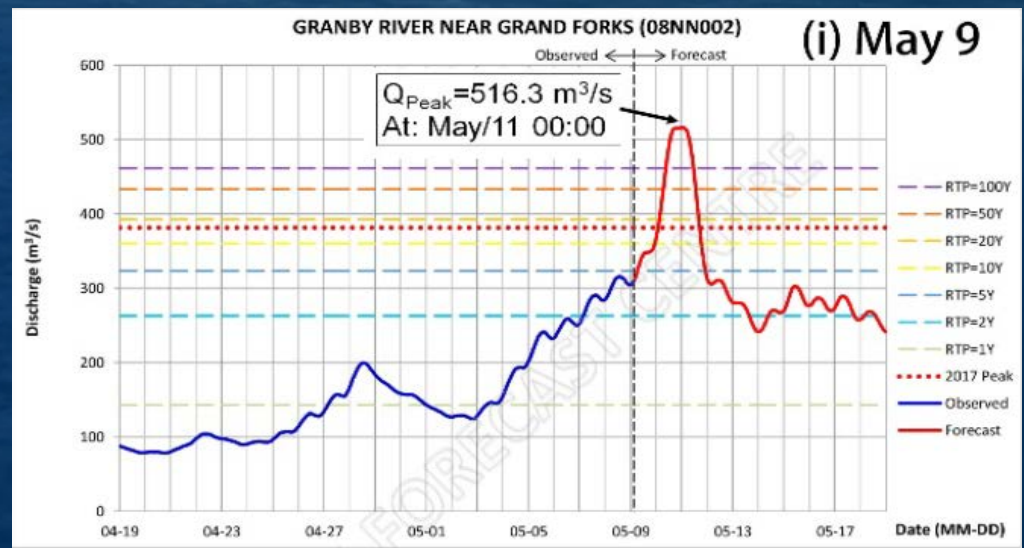
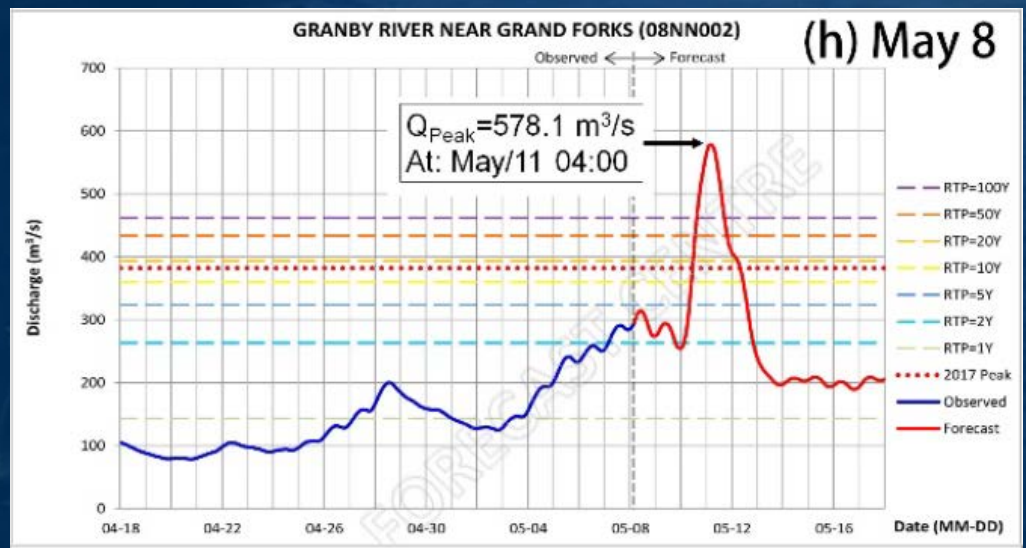
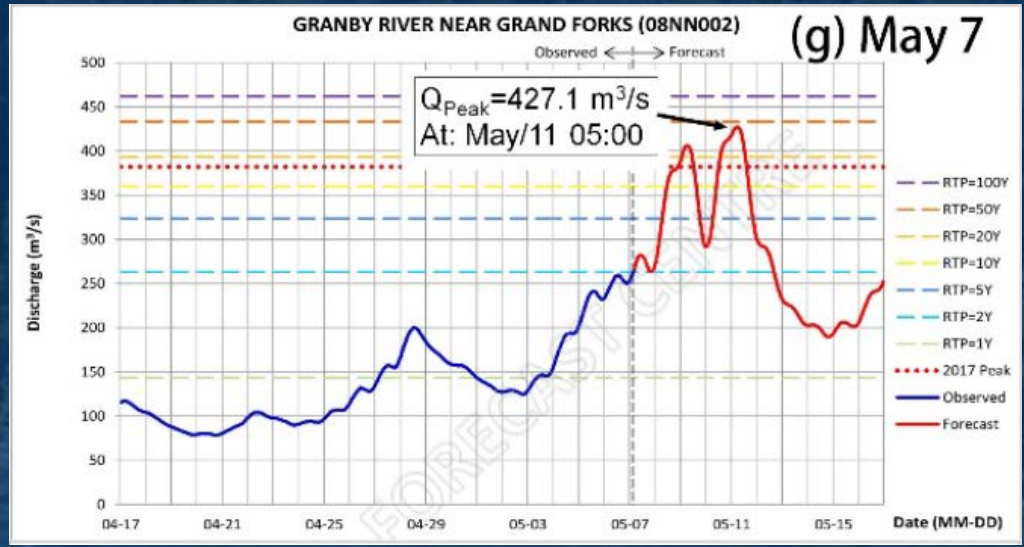
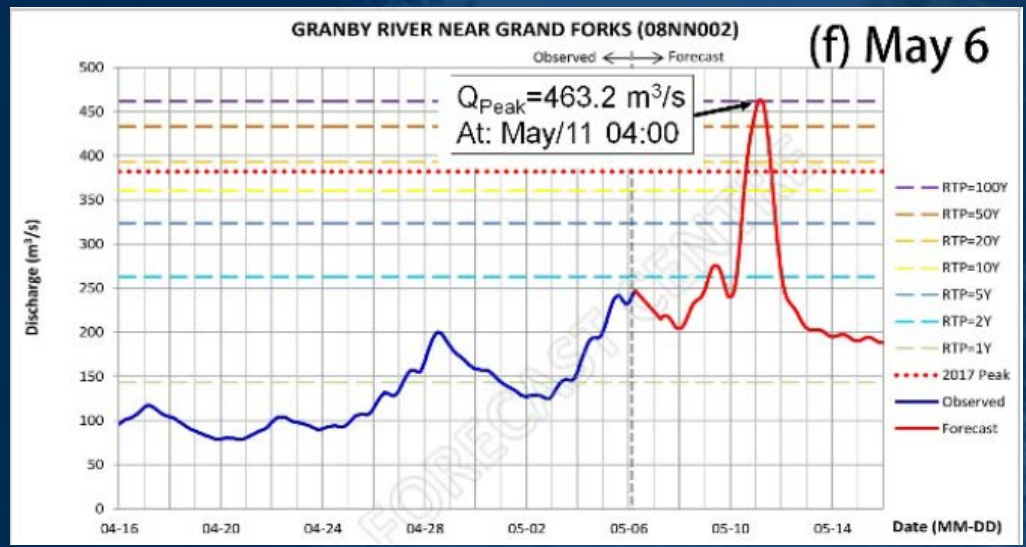
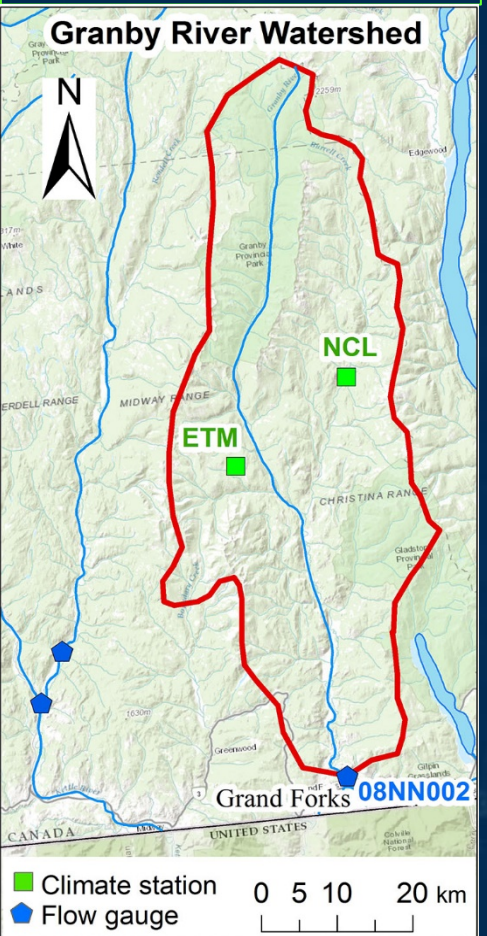


# 10. Post freshet review of model performance

– statistics and flooding events



**Review of Granby  
May 10, 2018 Flood  
(3:55 p.m. PST)  
(Observed Q peak =  
524 m<sup>3</sup>/s)**





# 10. Post freshet review of model performance

– statistics and flooding events

(78 pages) **River Forecast Centre**

Review of Early July 2019 Chilcotin River Flood from Perspective of Hydrologic Modeling Efforts

Charles Luo, Ph.D., P.Eng.

River Forecast Centre, May 2020

[http://bcrfc.env.gov.bc.ca/freshet/cleverm\\_ref/ChilcotinFlood2019July\\_lr.pdf](http://bcrfc.env.gov.bc.ca/freshet/cleverm_ref/ChilcotinFlood2019July_lr.pdf)

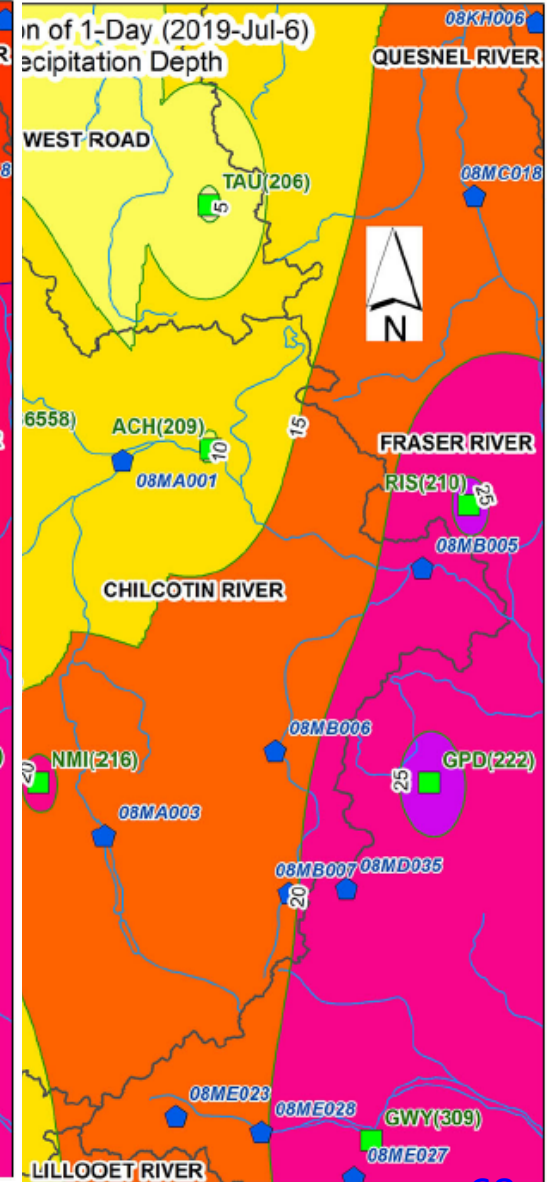
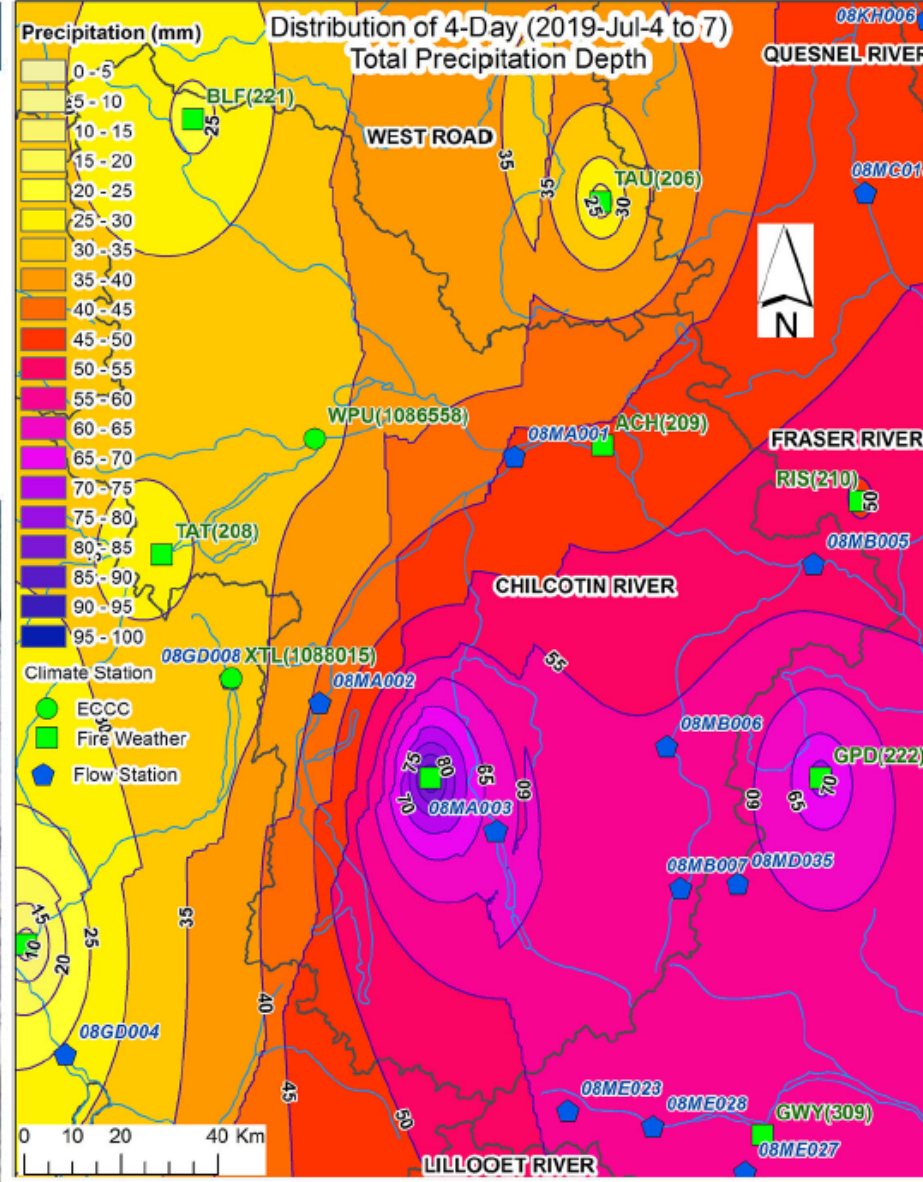
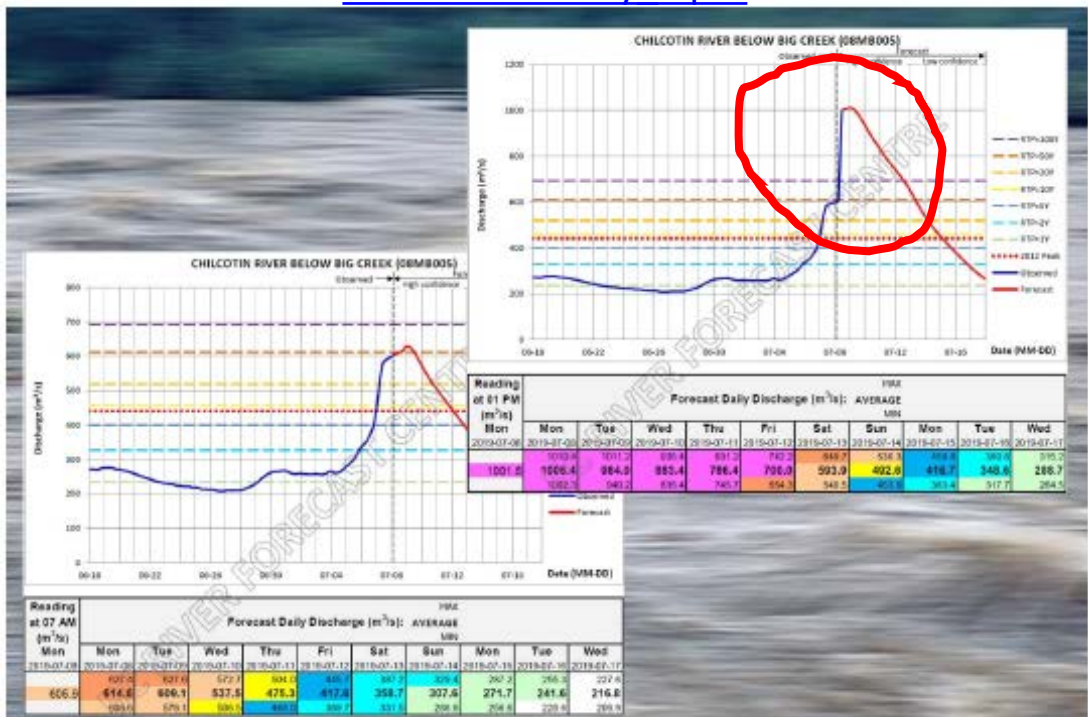


Figure 8. Isohyet map of 4-day (July 4 to 7, 2019) total precipitation depth in Chilcotin River watershed and 1-day depth in Chilcotin River watershed, July 6, 2019

# 11. Modeling uncertainties – understanding limitations



First category of modeling uncertainties coming input data

Forecast climate data (ECCC CMC NWP Grib2 Regional MD 10km/ global MD 25km) and downscaling to clim. st

Observed climate data: missing and interpolation/ extrapolation

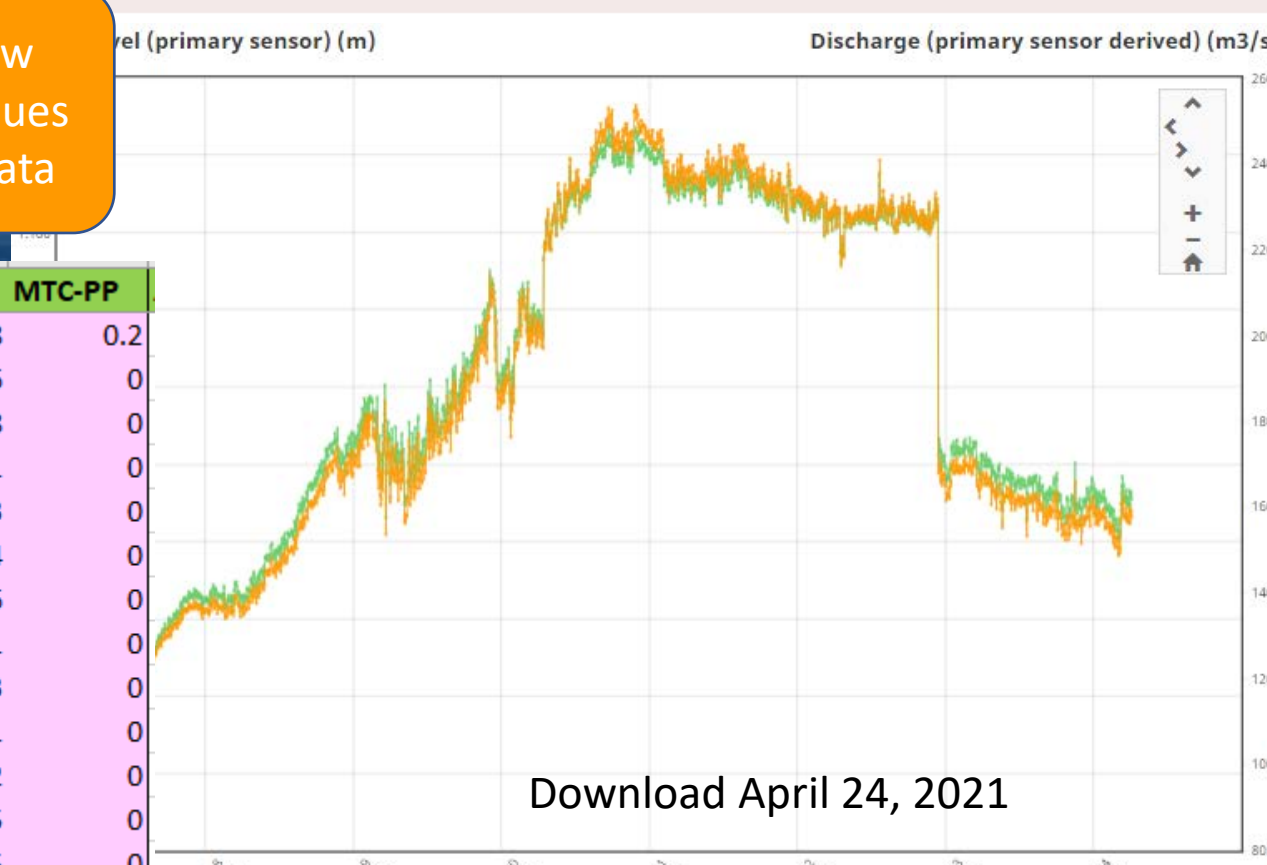
Observed flow data: gauge issues and missing data

DATE	CHP-TX	CHP-TN	CHP-PP	SPZ-TX	SPZ-TN	SPZ-PP	MTC-TX	MTC-TN	MTC-PP
2021-04-10	-4.6	-6.6	0	5.2	-3.1	13	3	-4.8	0.2
2021-04-11	-1.3	-8.6	0	5.5	-9.9	0	2.9	-9.6	0
2021-04-12	7.5	-5.7	0	4.8	-7.1	0	5.6	-8	0
2021-04-13	12.7	-7.1	0	9.7	-5.6	0	9.7	-11.1	0
2021-04-14	17.9	-4.6	0	14.1	0.4	0	16.2	-9.3	0
2021-04-15	14.5	-2.4	0	17.4	0.4	0	18.5	-8.4	0
2021-04-16	16.9	6.5	0	19	2.3	0	19.5	-7.6	0
2021-04-17	18.2	9	0	19	1.6	0	20.7	-7.1	0
2021-04-18	13.3	8.2	0	17.3	1.1	0	9.3	-6.3	0
2021-04-19	9.9	3.3	0	17.2	1.2	0	12.3	-3.1	0
2021-04-20	11.9	4.8	0	16.4	0.2	0	15.9	-9.2	0
2021-04-21	12.4	5.2	0	13.6	-0.3	0	15.1	-7.5	0
2021-04-22	8.2	2.1	0	12.6	-0.7	0	7.6	-1.5	0
2021-04-23		0.2			-1			-7.8	

**Missing data**

## Real-Time Hydrometric Data Graph for WEST ROAD RIVER NEAR CINEMA (08KG001) [BC]

**Station Notice**  
The regular flow measurement program at this hydrometric gauge is compromised because the cableway is currently out of service. Please email [ec.shnhydrologiquebc-nhshydrologicalbc.ec@canada.ca](mailto:ec.shnhydrologiquebc-nhshydrologicalbc.ec@canada.ca) with any questions or concerns.



Download April 24, 2021



# 11. Modeling uncertainties – understanding limitations

Second category of modeling uncertainties  
coming from the model itself

## Model intrinsic limitations

Watershed routing

Simplifying a basin into a single node

Simplifying hydrologic cycle: Evp, Inf, GD, SM

Lack of overland flow routing

Using daily data to distribute into hourly

Open channel routing

Kinematic wave simplification of SV Eq.

Finite difference solution of KW Eq.

Simplification of cross-section into a rectang.

Lack of data of channel dimensions (42,150 km)

## Model operational limitations

Parameters calibrated in previous years may have changed without recent hydrologic indicators

Too many parameters to calibrate – wrong combination of parameters for correct results

Too short time for model calibration – lower accuracy






Modelers' experience





# 12. Types of modeled stations

The only type of stations included in the model when developed and in early stage of operation (watersheds were split originally based on WSC stations)

- FLOW STN**
-  WSC\_ACTIVE
  -  WSC\_INACTIVE
  -  NON\_WSC
  -  ESTIMATED
  -  ROUTING

1. After April 2018 West Road River/Nazko River flood, the inactive WSC station NAZKO RIVER ABOVE MICHELLE CREEK (08KF001) was added because of flooding concerns.
2. After July 2019 Chilcotin River Flood, WSC eliminated the CHILCOTIN RIVER BELOW BIG CREEK (08MB005), which was kept in the model as an inactive station for better model calibration.
3. PEACE RIVER AT HUDSON HOPE (07EF001) became inactive in 2019 and removed from the model in 2020. It was restored in the model as an inactive station in 2021 for better model calibration.
4. Because of flooding concerns, the SOMASS RIVER NEAR ALBERNI (INACTIVE STATION) (08HB017) was included when VI basins were included in the model as of 2020.

The only Non-WSC station is the LILLOOET RIVER FSR (08MG00A) (BC station ID: 08MG0001), an important station for Pemberton.

